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COMPARISON OF MAXIMAL AEROBIC CAPACITY AND MAXIMAL AEROBIC POWER AS MEASURES OF ENDURANCE FITNESS

by

© GLEN EDWARD BAILEY

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "COMPARISON OF MAXIMAL AEROBIC CAPACITY AND MAXIMAL AEROBIC POWER AS MEASURES OF ENDURANCE FITNESS" submitted by GLEN EDWARD BAILEY in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Physical Education.

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ABSTRACT

Measurements of ventilation rate ($\dot{V}e$) and venous blood lactate (Lv) were made during an incremental continuous work test on a bicycle ergometer (six work-loads incremented 1/2 kp. every four minutes). For each subject, the level of work below which $\dot{V}e$ became non-linear with increasing work-load was calculated. Similarly, the level of work below which Lv increased above the resting level was determined. This level of work was termed the maximal aerobic capacity (MAC). The MAC was calculated separately from the ventilation curves [MAC ($\dot{V}e$)] and lactate curves [MAC (Lv)] to determine how closely ventilation changes followed lactate changes during the incremental test. The major purpose of the study was to correlate the MAC measurements with two endurance runs of twelve and thirty minutes duration and statistically compare these correlations against the corresponding correlations with the $\dot{V}O_2$ max. Correlations of the twelve and thirty minute runs with the MAC were compared for a significant difference and this procedure was repeated in relation to the $\dot{V}O_2$ max. A general comparison of the coefficient of variation for each test was made. The tests were completed on 26 volunteer subjects (19-31 years). Activity levels ranged from relatively sedentary individuals to endurance athletes.

The results indicated no significant differences between the MAC ($\dot{V}e$) and MAC (Lv), expressed in absolute and relative terms. The correlation between the two methods of determining the MAC was 0.87 (work-loads). Values for the MAC ($\dot{V}e$) had higher correlations with the relevant variables than the MAC (Lv). The MAC ($\dot{V}e$) expressed as $\dot{V}O_2$

(ml/kg/min.) had the best correlations with the relevant variables compared to the other relative values determined. The correlation of the MAC (Ve) with the twelve minute run (r = 0.77) was not significantly different from the corresponding correlation with the $\dot{V}O_2$ max. (r = 0.76). The correlation of the MAC (Ve) with the thirty minute run (r = 0.72) was not significantly different from the corresponding correlation with the $\dot{V}O_2$ max. (r = 0.67). The correlation of the twelve minute run with the MAC (Ve) [r = 0.77] was not significantly different from the corresponding correlation with the thirty minute run (r = 0.72). The correlation of the twelve minute run with the $\dot{V}O_2$ max. (r = 0.76) was not significantly different from the corresponding correlation with the thirty minute run (r = 0.67). The MAC (Ve) as $\dot{V}O_2$ (ml/kg/min.) and the $\dot{V}O_2$ max. (ml/kg/min.) had a correlation of 0.82. The relative variation of the MAC was twice that for the other three tests and the scores were more clearly separated.

It was concluded that the MAC may be determined from measurements of ventilation rate during an incremental work test, excluding the need for blood sampling. The MAC test appears to distinguish fitness levels more clearly than the $\dot{V}O_2$ max. The MAC measurement appears to be at least as good as the $\dot{V}O_2$ max. in predicting endurance performance. Since the MAC test does not require maximal effort and results are directly measured, the test has wide application in the various areas of fitness evaluation.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

A great variety of work-tolerance tests have been developed over the years in an effort to objectively measure man's capacity for physical work. A number of authors (54, 118, 120, 127) have recently reviewed the principle tests that have been, or are currently accepted as valid measures of physical work capacity.

There are a number of components of work capacity, of which the most important is considered to be an individual's capacity to perform prolonged work - termed endurance capacity or endurance fitness. These terms may be clarified as the ability to perform work for prolonged periods with the involvement of large muscle groups, without excess fatigue, and the ability to recover quickly and completely from this work (35).

The measurement of aerobic power - the $\dot{V}O_2$ max. either directly (94, 116, 118, 120, 125, 139) or indirectly (6, 26, 37, 90, 92, 106) has long been considered the best single indicator of an individual's ability to perform prolonged work (1, 6, 7, 9, 28, 29, 35, 94, 111, 116, 139, 141) and test procedures have been standardized to measure this variable in the laboratory (116) and in the field (117). Recently, however, there have been arguments against the use of the $\dot{V}O_2$ max. as a measure of endurance fitness (32, 35). Davies (35) has stated that the $\dot{V}O_2$ max. is more a

measure of the potential for endurance work and is not necessarily a good indicator of the capacity for exercise. In addition, the $\dot{V}O_2$ max. tells very little about the state of training of an individual. Davies (35) suggested that a determination of maximal aerobic capacity would provide more information concerning an individual's endurance fitness. Davies (34), in an earlier paper, qualified this term as the highest rate of work which can be performed by purely oxidative means without the occurrence of anaerobic metabolism (above resting levels), and therefore continued for prolonged periods without undue fatigue (34). This term should not be used to denote the determination of $\dot{V}O_2$ max.; for which the correct term is the maximal aerobic power.

In the past, the assessment of the level of exercise at which lactate in the blood increased above resting levels (the anaerobic threshold), involved almost continual sampling of blood; an elaborate and time consuming procedure and which could also be of some discomfort to the individual. Recently, a number of non-invasive techniques have been studied, in which the anaerobic threshold may be determined from a series of short work tests (33, 34, 56, 136) or from an incremental continuous work test (97, 129, 131, 132, 133). In studies by Harris and Porter (56), Davies and Harris (33) and Davies (34) the pulse-deficit of early exercise was used to detect the anaerobic threshold. The pulse-deficit was defined as the number of heart beats by which the total count in the first half of the exercise (6 to 10 minutes duration) fell

short of the total heart beats measured in the second half of the exercise. These authors showed that the pulse-deficit of early exercise remained at or near zero at work rates below the anaerobic threshold. At work rates above the threshold, pulse-deficit increased sharply and corresponded to the non-linear increase in oxygen-debt, a fall in $PaCO_2$*(56) and an increase in R**(34); these being the variables used to indicate the onset and degree of anaerobic metabolism. Whipp and Wasserman (136) showed that the difference in $\dot{V}O_2$ between the third minute and sixth minute was zero at work intensities below the anaerobic threshold, and greater than zero above the threshold. The magnitude of the difference corresponded to concomitant increases in arterial blood lactate and decreases in plasma bicarbonate as work intensities were increased. A simpler and less time consuming procedure for detecting the anaerobic threshold was shown by Naimark et al. (97), Wasserman and McIlroy (129), and Wasserman et al. (131) by employing an incremental work test on the bicycle ergometer. From the continuous monitoring of expired air by rapidly responding gas analyzers, it was demonstrated that R increased above the resting level at the same time that arterial blood lactate increased and plasma bicarbonate decreased - indicating the onset of anaerobic metabolism (97, 129). In later studies (131, 133), it was shown that $\dot{V}e$ and $\dot{V}CO_2$ increased out of proportion to $\dot{V}O_2$ at the same work rate at which lactate and bicarbonate began to increase and decrease, respectively. Wasserman et al. (133) noted

* Pa CO_2 = partial pressure of arterial CO_2

** R = respiratory quotient

that a determination of $\dot{V}e$ or $\dot{V}CO_2$ in relation to $\dot{V}O_2$ was a more sensitive indicator of the anaerobic threshold than a calculation of R. The results clearly indicated that the anaerobic threshold (and hence an individual's maximal aerobic capacity) could be accurately determined in a single testing session from easily determined measurements of $\dot{V}e$ and $\dot{V}CO_2$ in relation to $\dot{V}O_2$ or work-load. These measurements indicated that blood sampling is not required to detect the anaerobic threshold.

Since the $\dot{V}O_2$ max. has been considered a measure of endurance fitness, considerable research has been conducted in determining the relationship between this variable and some form of endurance test. In various types of running performance the correlations have ranged from .34 to .90 with the $\dot{V}O_2$ max. (76, 77), and a correlation of -.91* has recently been reported for highly trained endurance athletes (24). Less research has been completed in which the bicycle ergometer was employed to measure endurance in relation to $\dot{V}O_2$ max. but relatively low correlations have been reported (76, 78, 138).

Some authors (46, 47, 48) favour an endurance test to exhaustion, but in tests of this type there are problems with motivation of the subject, the time involved and in defining the end point of exhaustion (35, 78, 118, 120). To obviate the problems of motivation, etc. and to determine the optimum time for an endurance run, Balke (12) and subsequently Cooper (19, 20, 21) demonstrated that a twelve minute run-walk was a valid

* In interpreting the correlations cited throughout the study, it should be recalled that where time or order of finish is used, a negative correlation coefficient results.

measure of endurance, using $\dot{V}O_2$ max. as the criterion of validity. In a run of this duration, it was found that the subject would conform to a pace which was matched most closely to his aerobic power. Similarly, Katch (78) demonstrated recently that the optimum time for an endurance performance on the bicycle ergometer in relation to $\dot{V}O_2$ max. was twelve minutes.

In a self-paced endurance test of two miles (approximately twelve minutes in time) it is not certain as to how much energy is derived from anaerobic sources - particularly from the pyruvate→ lactate mechanism. Presumably the major energy requirements are met by current oxygen consumption (77) and Katch and Henry (77) have shown that an estimate of maximal oxygen debt added to the measurement of $\dot{V}O_2$ max. did not improve the prediction of two mile running performance.

It appears that when an individual's maximal aerobic capacity is a high percentage of his aerobic power, such as in endurance athletes (24, 35), the correlation between running performance and $\dot{V}O_2$ max. is high, at least when the running performance is of relatively short duration (24). In running performance of 2 to 3 hours (endurance athletes), there appears to be no relationship with the $\dot{V}O_2$ max. (23). For untrained individuals, the generally low correlations between endurance performance (short duration) and $\dot{V}O_2$ max. may reflect a low aerobic capacity in which the individual is unable to make use of his potential capacity, as measured by the $\dot{V}O_2$ max. (35). Costill et al. (23, 24) have recently shown that

success in distance running is dependent on the ability to utilize a high percentage of the $\dot{V}O_2$ max. concomitant with minimal accumulation of lactic acid. In these two studies, however, the exact maximal aerobic capacity in relation to the $\dot{V}O_2$ max. was not determined on each athlete. An accurate determination of maximal aerobic capacity in relation to an endurance performance compared to the $\dot{V}O_2$ max. and endurance performance, may possibly show a higher degree of relationship.

The Problem

In view of the preceding discussion, the objectives of the present investigation were:

1. To verify the relationship between changes in blood lactate and changes in ventilation during an incremental work test to determine the MAC (as defined),
2. a. To correlate the twelve minute run-walk with the MAC and the $\dot{V}O_2$ max. and test for a significant difference between the two correlations,

   b. To correlate the thirty minute run-walk with the MAC and the $\dot{V}O_2$ max. and test for a signficant difference between the two correlations,
3. To test for significant differences between:

   a. the correlations of the twelve and thirty minute run-walks with the MAC,

   b. the correlations of the twelve and thirty minute run-walks with the $\dot{V}O_2$ max., and

4. To generally compare the coefficients of variation (standard deviation/mean) between the four tests.

Justification for the Study

Although lactate appears in the blood (above resting levels) at a higher percentage of $\dot{V}O_2$ max. while running than during cycling (79), the bicycle ergometer was chosen as the test instrument vs. the treadmill for a number of reasons:

1. Blood sampling is better facilitated when using the bicycle ergometer,
2. Work-loads are more easily chosen and the calculation of work-loads is simpler,
3. Since the bicycle ergometer is the test instrument of choice in field surveys, it is necessary to determine how well the measure of maximal aerobic capacity relates to endurance performance when using this instrument, and
4. None of the subjects in the study had any training in bicycling, except one, and this subject was also a distance runner. Therefore, it was assumed that there would be no directional bias between the subjects on their performances in the four tests (100).

An assessment of maximal aerobic capacity has been determined in a number of studies, but the relationship of endurance performance to an accurate measure of maximal aerobic capacity has not been tested, although Costill et al. (24) approached this problem from a different aspect. In the study, the $\dot{V}O_2$ (as a percentage

of $\dot{V}O_2$ max.) and heart rate (as a percentage of maximal heart rate) were measured on sixteen endurance athletes while running on a treadmill at 268 meters/min. The results were correlated with a 10 mile run for time. It was found that percent $\dot{V}O_2$ max. and percent maximal heart rate were highly related to the endurance run (-0.94 and -0.98 respectively). However, an exact measurement of maximal aerobic capacity was not measured in the athletes. If the relationship between an exact measure of maximal aerobic capacity and endurance performance is found to be better than that between the $\dot{V}O_2$ max. and endurance performance the information has implications for further research in the laboratory and in the field. Further research could include:

1. The development of a standardized technique for measuring the maximal aerobic capacity for field surveys, and the development of norms for various segments of the population,
2. Industrial application,
3. A comparison of the maximal aerobic capacity between the bicycle ergometer and the treadmill in relation to the $\dot{V}O_2$ max. and endurance performance, as measured on both ergometers,
4. A determination of the relationship between the maximal aerobic capacity and other physiological variables including the percentage of muscle fiber type in the relevant muscle groups etc., and

5. A determination of the effects of different kinds of training on the maximal aerobic capacity in relation to other physiological variables.

Delimitations

The study was limited to 30 male volunteers (19 to 31 years of age) including physical education students of varying fitness levels and members of the University of Alberta track team.

Limitations

The choice of endurance tests limited to twelve and thirty minutes duration may be too brief to reflect a good estimation of endurance performance. However, the choice of an endurance test of this type depends on how well the test relates to some other independent measure of endurance capacity. Thus, it was shown that a run of twelve minutes duration related best to the $\dot{V}O_2$ max. vs. runs of shorter or longer duration (86). A run of thirty minutes duration was included in the study to determine if there was any difference in the correlations compared to the twelve minute run. The endurance runs were chosen also to mitigate the problems of motivation etc. which are inherent in endurance tests to exhaustion (118).

Definition of Terms

Aerobic power ($\dot{V}O_2$ max.) - the ability of the oxygen transport system to take up, transport and give off oxygen to the working muscles (1, 7, 28, 35, 108, 109). This classical concept of the

$\dot{V}O_2$ max. has recently been challenged on the basis of findings that suggest that $\dot{V}O_2$ max. may measure the capacity of muscle to consume oxygen. There are many arguments for and against the two concepts, and at present the problem has not unequivocally been solved (60, 109). In the present study the $\dot{V}O_2$ max. was determined on the bicycle ergometer after the method of Astrand (5) as modified by Macnab et al. (87). The precise work-load at which the $\dot{V}O_2$ max. 'levelled-off' was determined.

Anaerobic threshold (AT) - the work-rate at which anaerobic metabolism (pyruvate→ lactate mechanism) becomes a factor in the total energy output as measured by a continuous incremental work test (133). At this work rate and above, lactate utilization (16, 66, 72, 107) does not keep pace with lactate production as indicated by an elevated blood lactate above the resting value. The AT may also be defined as the level of work below which a subject may perform for prolonged periods, without increasing blood lactate above the resting level (see maximal aerobic capacity).

Blood lactate - lactic acid in the blood which is in a combined state with the blood buffers. Lactic acid is the end product of anaerobic glycolysis, and is used as an indicator of the extent to which the pyruvate→lactate mechanism has been utilized during exercise (135) i.e. when lactate production exceeds utilization above the resting value.

Endurance capacity (fitness) - the ability to cover the greatest distance possible on a level 440 yard track while performing a

self-paced run walk in (1), a time period of twelve minutes and (2), a time period of thirty minutes.

Maximal aerobic capacity (MAC) - according to Davies (34), is the highest rate of work which can be performed by purely oxidative means without the occurrence of anaerobic metabolism and therefore continued for prolonged periods without undue fatigue. The above definition is not entirely correct since there is always some degree of anaerobic metabolism proceeding during exercise. The lactate that is produced by the working muscles is utilized by various organs of the body (16, 66, 72, 81, 107). Utilization keeps pace with production up to a particular work level such that the lactate level in the blood remains at or close to the resting value. This level of work is correctly termed the maximal aerobic capacity. At work-rates above this, lactate production exceeds utilization and the level in the blood exceeds the resting value (see anaerobic threshold).

Pulse-deficit of exercise - refers to short-term work of 6-8 minutes duration. It is the number of heart beats by which the total count during the first half of the exercise falls short of the total count during the second half of the exercise.

Plasma bicarbonate - a buffering agent in the blood which serves to maintain blood pH within physiologic limits.

Ve - expired ventilatory volume measured in litres per minute.

CHAPTER II

REVIEW OF THE LITERATURE

The $\dot{V}O_2$ max. as a Measure of Endurance Fitness

Since the work of Hill et al. (61c) in the 1920's, the measurement of $\dot{V}O_2$ max. has received considerable attention, both in the laboratory and in the field (35). A number of methods have been developed to measure this variable directly (94, 116, 118, 120, 125, 139) or indirectly (6, 26, 37, 90, 92) and standardized procedures have recently been recommended for both techniques (116, 117).

The measurement of $\dot{V}O_2$ max. is currently held as being the best single indicator of endurance fitness - that is, the ability to perform work, employing large muscle groups, for extended periods of time (1, 6, 7, 9, 28, 29, 35, 94, 111, 116, 139, 141). The $\dot{V}O_2$ max. has been described as the ability of the oxygen transport system to take up, transport, and give off oxygen to the working muscles (5). Andersen (1) stated that the capacity to deliver energy for muscle contraction is a fundamental characteristic of the fitness for work and Astrand (7) wrote that an individual's maximal physical performance was determined by the capacity of the energy delivering processes and mechanical efficiency; therefore the individual capacity for oxygen intake ($\dot{V}O_2$ max.) should be decisive in the ability to sustain heavy prolonged work. The above definitions are the classical view of the $\dot{V}O_2$ max. but, as mentioned previously in Chapter I, there is now evidence to suggest

that the $\dot{V}O_2$ max. is a measure of the capacity of muscle to consume oxygen (60, 109). Rowell (108) described the $\dot{V}O_2$ max. as the ability to perform prolonged moderate to heavy work, provided that large muscle groups are used. It is a measure of the functional capacity of the cardiovascular system in the absence of pulmonary pathology. Rowell favours the $\dot{V}O_2$ max. as a measure of endurance fitness by citing the example of comparing an individual with a $\dot{V}O_2$ max. of 70 ml/kg/min. with an individual whose $\dot{V}O_2$ max. is 40 ml/kg/min. (body weights equal). When performing prolonged work at a fixed work load, the unfit individual is working at a higher percentage of his $\dot{V}O_2$ max. compared to the fit man, and will fatigue sooner. Rowell stated that this provides the most obvious basis for the marked difference in performance capacity of the two individuals. There still remains, however, considerable discrepancy in predicting accurately an individual's endurance capacity from a knowledge of his $\dot{V}O_2$ max. (29, 35), although some exceptions have been reported in the literature (19, 24).

Reasons for the discrepancy in predicting endurance capacity from measurements of $\dot{V}O_2$ max. have been postulated by Davies (35). Davies clarified the difference between aerobic capacity and aerobic power. The maximal rate at which oxygen may be consumed by an individual is termed the aerobic power ($\dot{V}O_2$ max.). Additional power to perform work-loads above that which elicits the $\dot{V}O_2$ max. may be gained from anaerobic sources, but only for brief periods. The total amount of energy available denotes the capacity of the above systems. Theoretically, aerobic capacity is infinite, but

aerobic mechanisms may be limited by muscle nutrition, peripheral circulation, thermo-regulation and fluid balance. Davies stated that although an assessment of aerobic power may be an important measure in determining work performance at high rates from one minute to one hour, beyond this time the aerobic capacity is more decisive. The $\dot{V}O_2$ max. is more a measure of the potential for endurance work. Even though an individual has a high $\dot{V}O_2$ max. through genetic endowment, the individual may not have the ability to utilize this power if not in a trained state. The $\dot{V}O_2$ max. may tell very little about prior training since it appears that this variable is predominantly determined by heredity (10, 35, 60). The greatest effect of training seems to be a greater co-ordination of the oxidative mechanisms (35), a decreased accumulation of anaerobic metabolites (10, 31, 43, 75, 81) and not a large increase in $\dot{V}O_2$ max. (10, 35, 46). It has recently been shown that endurance time on a bicycle ergometer may be doubled after a short period (five weeks) of training (at 75% of $\dot{V}O_2$ max.) but that the $\dot{V}O_2$ max. was increased only 7% (46).

There has been little attempt to measure maximal aerobic capacity in different population samples by measuring the length of time that an individual can work at a given percentage of $\dot{V}O_2$ max. without the occurrence of accumulation of blood lactate, and ultimately define the maximum capacity for aerobic work for given periods of time. There are apparent difficulties in studies of this type, such as the length of time involved and defining exactly

the 'end point' of work (35). A different approach has been pursued recently to measure maximal aerobic capacity from a series of short work-tests (33, 34, 56, 136) or from a continuous incremental work-test (97, 129, 131, 132, 133).

Measurement of Maximal Aerobic Capacity (MAC)

A measurement of MAC, as opposed to the measurement of aerobic power, assumes that most of the energy is derived from aerobic oxidation. Davies (34) defined MAC as the highest rate of work which can be performed by purely oxidative means without the occurrence of anaerobic metabolism and therefore continued for prolonged periods without fatigue (see Chapter I for revised definition). In the past, determining the work level at which lactate increased above resting levels involved almost continuous sampling of blood; an elaborate and time consuming procedure. However, a number of methods for determining the threshold of anaerobic metabolism by non-invasive techniques have recently been presented.

In 1958, Harris and Porter (56) studied the relationships between heart rate, oesophageal temperature, oxygen debt and $PaCO_2$ on one subject at eight different intensities of work on the treadmill. Each work test lasted 10 minutes. Among the various heart rate characteristics measured, one was the pulse-deficit of exercise - defined as the number of heart beats by which the total count (measured every 30 seconds - the first starting at 30 seconds) in the first five minutes fell short of the total heart beats (measured every 30 seconds) in the second five minutes. The authors

found that the pulse-deficit remained at or near zero until an oxygen uptake of about 2 l/min. At this work rate and above, the pulse-deficit increased significantly and corresponded to a sudden rise in oxygen debt and a fall in $PaCO_2$. According to the authors, the sudden changes in oxygen debt and $PaCO_2$ at the particular work rate, marked the beginning of anaerobic metabolism for this subject. The pulse-deficit was the only variable measured which bore a relationship with the alactic-lactic threshold and the authors concluded that this may be one of the very few reliable indices of an individual's capacity for exercise.

Davies and Harris (33) extended the study of the pulse-deficit of early exercise on fifteen subjects (male and female) in whom the $\dot{V}O_2$ max. was indirectly measured. A pulse-deficit index was determined as the lowest $\dot{V}O_2$ (l/min.) at which the pulse-deficit showed a decided upward swing. Three standard indices of work capacity were also determined. These included the PWC_{170}, the Leistungspulsindex (in beats/liter) and the aerobic capacity - calculated as the $\dot{V}O_2$ corresponding to an exercise heart rate of 128 in males and 138 in females. The $\dot{V}O_2$ values were then doubled. For comparison between individuals, all data was corrected to a body weight of 65 kg. The $\dot{V}O_2$ max. was considered by the authors as being the best independent measure of work capacity. The results showed that the pulse deficit index (PDI^{65}) formed the best relationship with $\dot{V}O_2$ max.^{65} compared to the other indices of work capacity. In analysis of data from previous work, the PDI accurately classified an athlete, young men, young women and old

men, as groups, in a decreasing scale of exercise tolerance. The other standard indices of work capacity were not as accurate. In a more vigorous analysis, Davies (34) confirmed the relationship between the pulse-deficit of early exercise and the threshold of anaerobic metabolism, that was shown in previous studies.

Davies (34) commented that the pulse-deficit reflects the deficit in cardiac output in the early stages of exercise. The distinct rise in pulse-deficit parallels the rise in oxygen debt and R which marks the beginning of metabolic acidosis. It is still not clear why there are changes in, and a marked association between, heart rate (in early exercise) and the onset of anaerobic metabolism. The factors which regulate the circulation in exercise are complex, and have been discussed by a number of authors (4, 14, 15, 55, 109). Temperature increase may be one factor causing the gradual (secondary) rise in heart rate as has been argued by Shephard (119). However, Harris and Porter (56) corrected heart rate for the presumed effects of temperature, which did not change the characteristics of the pulse-deficit. The accumulation of anaerobic metabolites, such as lactate, do not appear to directly affect the heart rate (4, 33, 55). Although the aortic and carotid chemoreceptors are stimulated by such factors as low oxygen tension, increases in CO_2 and a lowered pH, the effects on the heart rate appear to be secondary to the potent enhancement of pulmonary ventilation (10, 14). The stimulus which initiates the increase in cardiac output and keeps it at a working level, appears to be, in some way,

closely associated with the intensity of work (4, 34, 109). Rowell (109) has stated that exercise increases sympathetic nervous activity to the heart and visceral organs in direct proportion to the relative severity of the exercise. This does not, however, explain the secondary rise in heart rate at the anaerobic threshold of exercise and above. Complete answers to this question remain to be found.

Determining a pulse-deficit index has one important advantage over other tests based on heart rate. The actual heart rate or pulse-deficit in a given subject does not enter into the comparison with other subjects. Once the $\dot{V}O_2$ at which pulse-deficit shows a marked increase has been determined, the heart rate is no longer needed, nor is the precise rate at which the exercise heart rate or pulse-deficit increases with increasing $\dot{V}O_2$ (33). Other advantages of the test are simplicity and safety, and the pulse-deficit index is independent of sex and age; being related primarily to the fitness of the individual (33, 34). This appears to be true when the PDI is expressed in relative terms. Fitness level is related to sex and age when, for example, the $\dot{V}O_2$ max. is used as the measure of fitness (10, 11). The disadvantages are that the test procedure is time consuming and there are many factors which may affect submaximal heart rate (126).

Whipp and Wasserman (136) took a similar approach to the above work in a study of the oxygen uptake kinetics at various intensities of short-term exercise (six minutes). The authors

discovered that at low work loads the $\dot{V}O_2$ reached a steady-state in 2 - 3 minutes, but at higher work intensities the steady-state was reached progressively later. Measurements of arterial blood lactate showed that the $\dot{V}O_2$ which reached a delayed constant value was associated with anaerobic metabolism. If the difference in $\dot{V}O_2$ between the third and sixth minute was zero, the work rate was below the anaerobic threshold, and greater than zero at work rates at and above the anaerobic threshold. These findings would seem to agree with the work of others (33, 34, 56) on the pulse-deficit of early exercise.

A different approach in detecting the anaerobic threshold (determining the aerobic capacity) has been taken by other investigators. It has been shown that the ventilatory gas exchange ratio (R) increases with increasing work intensities of short duration (69) and this change in R during short periods of exercise has been used in the assessment of physical fitness and working capacity (70). The rise in R is apparently due to (besides the metabolic R which is dependent on the substrate being utilized) the release of CO_2 from carbonic acid (18, 93) and is closely related to the increased concentration of lactate and the decreased concentration of CO_2 in blood (from an increased ventilation). The increase in R, which may interfere with the determination of metabolic R, can be a useful indicator of the point where lactate increases above the resting level in the blood, which may be assessed during a standard exercise test (97). Naimark et al. (97) measured R

continuously during exercise from end-tidal CO_2 and N_2 concentrations recorded with rapidly responding gas analyzers. Thirty-three normal subjects and ten patients with mitral stenosis or primary pulmonary hypertension exercised continuously on a bicycle ergometer or treadmill. Work loads on the bicycle ergometer were increased 150 to 300 kpm/min. every three to six minutes. The results indicated that the level of work at which R increased significantly above resting values, corresponded to the work level at which arterial lactate began to increase and plasma bicarbonate began to fall. The work load could then be determined at the point where anaerobic metabolism became a significant factor in energy expenditure. Wasserman and McIlroy (129) confirmed the findings of Naimark et al.

Wasserman et al. (131) extended the work previously reported, on ten healthy male students. The work rate at which R increased abruptly (the anaerobic threshold) was determined on each subject. Other measurements included $\dot{V}O_2$, $\dot{V}e$, $\dot{V}CO_2$, arterial blood lactate and plasma bicarbonate. From the results of the graded exercise test it was found that $\dot{V}e$ and $\dot{V}CO_2$ increased in proportion to $\dot{V}O_2$ to the point where the onset of metabolic acidosis became evident (changes in lactate and bicarbonate from control values). At this work rate and above, $\dot{V}e$ and $\dot{V}CO_2$ increased out of proportion to $\dot{V}O_2$ and the increase in arterial blood lactate closely paralleled the decrease in plasma bicarbonate. In a second part of the study three different work-loads were chosen which were performed by each subject for 50 minutes or until exhaustion. One work-load was just below the anaerobic threshold (the maximal aerobic capacity) and

the other two were 700 and 1500 ml/min. of oxygen consumption above the first, after the work classification of Wells et al. (134). At each work intensity, heart rate, $\dot{V}O_2$, arterial blood lactate, plasma bicarbonate, R., etc. were periodically measured. The results of these studies showed that the steady-state time for oxygen consumption was dependent on work intensity, i.e. the time arterial blood lactate concentration stopped increasing. At the lowest work-load, anaerobic metabolism was a very small part of the total energy expenditure but which increased significantly in the heavy and very heavy work. The increase in R was transient, that is, it decreased after steady-state was reached. These studies indicated that the anaerobic threshold was the level of work below which a subject may exercise for prolonged periods without developing metabolic acidosis.

Wasserman et al. (133) re-examined the relationships between R, $\dot{V}e$, $\dot{V}CO_2$, end-tidal O_2 and CO_2, arterial blood lactate and plasma bicarbonate on 85 subjects 17 to 91 years of age by comparing these responses during a 1 minute and 4 minute incremental work test. Work was performed on a bicycle ergometer starting at 0 load and incremented 150 kpm/min. A number of tests were performed on one subject over a nine month period to determine the repeatability of detecting the anaerobic threshold. Expired air-flow was monitored continuously with rapidly responding gas analyzers. As in previous studies, it was found that arterial blood lactate and plasma bicarbonate remained near resting levels until a work-load was reached at which oxygen supply could not

meet the demands of the exercising muscles. This concept is now questioned, since, for example, the critical level of venous PO_2 (10 mm Hg.) is never reached, even in very heavy exercise (60, 109). It appears that although electron transport becomes inadequate at a critical work rate which contributes to lactate production, oxygen is not the rate limiting metabolite (124). The magnitudes of the lactate increase and bicarbonate decrease were less for the 1 minute incremental test than for the 4 minute test, but changes from control values occurred at the same work intensity. $\dot{V}e$ and $\dot{V}CO_2$ became non-linear with $\dot{V}O_2$ at the point where arterial blood lactate and plasma bicarbonate became significantly (no statistics reported) different from control values. Changes in R were found to be the least sensitive in detecting the anaerobic threshold which was better visualized from the non-linear increases in $\dot{V}e$ and $\dot{V}CO_2$. The range of the anaerobic threshold varied approximately from 300 kpm/min. ($\dot{V}O_2$ of 1 l/min.) to 1080 kgm/min. ($\dot{V}O_2$ of 2.55 l/min.) in the subjects tested. The authors commented that since lactic acid has a low pK (at physiological pH) it is almost totally buffered in blood by bicarbonate, which decreases in approximately equimolar quantities. Because of the buffering action of bicarbonate, the $\dot{V}CO_2$ increases out of proportion to $\dot{V}O_2$ at work-loads at and above the anaerobic threshold. Since $\dot{V}e$ parallels $\dot{V}CO_2$, and because $\dot{V}e$ is so easily measured, it is an excellent indicator in determining the anaerobic threshold during an incremental test.

Control of Ventilation During Exercise

The stimulus or stimuli by which ventilation is controlled during exercise have still not been precisely determined. Many factors have been investigated, but in themselves, have been shown not to be a stimulus of the hyperpnea of exercise. These have included an increase in CO_2 production, a decrease in available oxygen, an increase in hydrogen ions, impulses from the motor cortex, mechanoreceptors in muscles or joints, other peripheral receptors such as 'ergoreceptors' in the limbs and conditioned reflexes (18, 95, 123). Asmussen and Neilsen (2) attributed the stimulus to some unknown substance X. Temperature, at least in moderate exercise, has been shown not to stimulate respiration (57). At present, it can only be stated that a number of variables are responsible, including known and unknown chemical stimuli acting on known and possibly unknown peripheral and central sites, temperature change and nervous influences; both reflex and central. It is also possible that the various stimuli may vary depending on the type of exercise, the intensity or the duration (18). Whatever the mechanisms are, Wasserman et al. (131) have concluded that the ventilatory control mechanisms favour the elimination of CO_2 rather than the delivery of oxygen in exercise, to ensure that the pH of the blood is maintained within a narrow range.

Endurance Tests

Tests on the Bicycle Ergometer

Many different tests have been used to measure actual endurance

performance (to exhaustion) on the bicycle ergometer as mentioned by Gleser and Vogel (46). Most of these tests have been employed for particular situations in analyzing a variety of variables, and none has emerged as a standard. More specific tests for measuring endurance capacity have been the Work max. 6 min. and the Work max. 90 min. employed by Tornvall (128) and Nordesjo (98). Wasserman et al. (131) used the work tests classified by Wells et al. (134) which were performed for 50 minutes or until exhaustion. Gleser and Vogel (46) studied the effects on endurance time using various work-rest schedules, in which subjects performed at approximately 75% of aerobic power (determined at the beginning of the study). It was found that different work-rest schedules did not affect endurance time significantly although subjectively, the subjects favoured the 18 minutes work - 2 minutes rest regimen. Endurance time was defined as the length of time a subject exercised until he could no longer maintain a pedal rate of 40 rpm. Endurance time (from repeated tests), doubled after the fifth week and peak serum lactate dropped significantly. The average $\dot{V}O_2$ max. increased 7.7%, but there was no correlation between individual increases in $\dot{V}O_2$ max. and endurance time. In further work Gleser and Vogel (47) demonstrated that endurance time on the bicycle ergometer could be accurately predicted from the equation:

$$\log (t) = A \cdot Lr + B \quad \text{where,}$$

Lr was the work load divided by $\dot{V}O_2$ max. and the parameters A and B described the individual's endurance capacity. In a further study (48) it was shown that the equation accurately predicted

endurance time under altered conditions of inspired oxygen. It was also shown that endurance time varied inversely with an approximate measure of anaerobic metabolism. Sen Gupta et al. (115) have recently shown that endurance time (at various work rates) may be accurately predicted from submaximal estimates of exercise ventilation and heart rate (expressed as percentages of maximal ventilatory volume and maximal heart rate).

In contrast, Katch (78) criticized the use of endurance tests to fatigue because of the long periods of time involved, problems with motivation and other complicating factors which might influence the performance. The objective in this study was to determine the optimal time for an endurance performance on the bicycle ergometer in relation to $\dot{V}O_2$ max. The method employed was to have each subject pedal at the same rate initially (69 rpm) at the same work intensity (1656 kpm/min.) for at least 12 minutes. As the test progressed, those with least endurance would fatigue first and vice-versa. The endurance score was the cumulated work accomplished for any particular minute. $\dot{V}O_2$ max. was correlated with each minute of accumulated work to validate the optimal time for endurance performance under these conditions. It was found that the correlations of $\dot{V}O_2$ max. with the minute-by-minute endurance scores increased progressively to $r = .78$ at minute 12. Katch concluded that $\dot{V}O_2$ max. does not predict endurance performance effectively unless it is continued for at least eight minutes and little further gains could be expected beyond 12 minutes.

Running Performance in Relation to $\dot{V}O_2$ max.

Although the bicycle ergometer has seldom been used to relate an endurance test to $\dot{V}O_2$ max., many studies have been completed employing some form of running performance and a number of methods have been recommended as standard tests of endurance fitness (12, 19, 20, 21, 86). The correlations between an endurance run and $\dot{V}O_2$ max. have varied considerably. Katch and Henry (77) reported a correlation of -.55 with two mile run time. $\dot{V}O_2$ max. was measured by an incremental test on a bicycle ergometer. Cooper (19) reported a correlation of .90 between $\dot{V}O_2$ max. and the distance covered in a 12 minute run-walk. Lavoie (86) related the $\dot{V}O_2$ max. (treadmill) to a 1000 meter run for time and a 12 minute run-walk for distance on 23 young adult males, and obtained correlations of -.70 and .65 respectively. Costill et al. (24) reported a correlation of -.91 between $\dot{V}O_2$ max. and the time for a ten mile race (distance runners). Of more significance, the authors found that at a selected speed of 268 m/min. (treadmill), the % $\dot{V}O_2$ max. and % H.R. max. were highly related to distance running performance (r = -.94 and -.98 respectively). Explanations for the variation in the relationship between $\dot{V}O_2$ max. and running performance are difficult to determine. Katch and Henry (77) reasoned that an estimate of maximal oxygen debt and the $\dot{V}O_2$ max. would predict 2 mile run times with substantial accuracy, but found that the two variables singly, or together, were poor predictors. The authors suggested that individual differences in motivation,

tolerance to pain or individual differences in strength may be involved. These factors would not seem to be involved in the results reported by Cooper (19), and his subjects were not well trained. They would not be a factor in the results reported by Costill et al. (24) since the subjects were highly trained and well motivated. In this study, the high relationship between $\dot{V}O_2$ max. and running time may have been due to the fact that the aerobic capacity of each runner was a high percentage of his aerobic power, i.e. the runners could make greater use of their potential capacity (35).

There has been considerable discussion as to what constitutes an endurance performance when the mode of exercise is running (86). Balke (12) has shown that best effort runs of 12 to 20 minutes duration related best to $\dot{V}O_2$ max. From the work of Balke, Cooper (19, 20, 21) developed a 12 minute run-walk test in which a particular distance covered corresponded to a particular range of $\dot{V}O_2$ max. values. From this test, an individual could, with reasonable accuracy, estimate his $\dot{V}O_2$ max. Knowlton and Gifford (82) studied two physiologically matched groups and their responses to two common field tests of aerobic capacity. The first test was the maximum distance covered in 15 minutes, performed by one group, and the other test was the average distance of test one performed in the minimum amount of time by the second group. It was found that the more appropriate field test (for inexperienced subjects) was a stipulated distance to be toured in a minimum time.

Little information is available on the contribution of anaerobic metabolism (pyruvate→lactate mechanism) on runs of 2 miles (approximate time of 12 minutes), particularly in self-paced efforts. If there was a substantial oxygen debt after a 2 mile run, then this would contribute to a prediction of 2 mile run performance. Katch and Henry (77) did not find this to be the case. However, the estimate of oxygen debt was determined from 'all-out' effort of one minute on the bicycle ergometer. Wasserman et al. (131) showed that in an endurance test on the bicycle ergometer (50 minutes duration) in which subjects worked at just below their anaerobic threshold, there was little contribution of energy from anaerobic sources. Keul et al. (80) have recently shown that untrained subjects were able to maintain average heart rates of 176 and 163 in endurance runs of one and two hours duration, respectively. Blood lactates peaked at the fifteenth minute and thereafter declined. Later lactate values were only slightly above resting values. The authors concluded that the relationship between lactate increase and heart rate during short lasting exercise is not valid in exercise of much longer duration. It appears reasonable to assume that in endurance tests where the subject paces himself, the predominant source of energy would be from aerobic oxidation, especially in performances beyond fifteen minutes.

Lactate Response to Exercise

Considerable evidence has been accumulated over the past 50

years demonstrating that the accumulation of lactate in the blood is related to either absolute and relative work-load (13, 17, 27, 36, 42, 48, 49, 58, 59, 61, 64, 65, 71, 73, 81, 83, 84, 85, 88, 89, 91, 96, 97, 101, 103, 110, 113, 114, 129, 130, 131, 133, 136, 137, 140). Margaria et al. (88) demonstrated that energy from anaerobic sources (the pyruvate → lactate mechanism) did not become significant until work rate became heavy (approximately 67% of $\dot{V}O_2$ max.). Subsequent research has shown that the work level at which lactate appears in the blood is primarily dependent on the fitness of the individual (5, 27, 33, 34, 104) and independent of sex and age (5, 33, 34). Training reduces the level of blood lactate for a given work-load (31, 43, 75, 80, 105, 112, 137, 142). The work intensity at which blood lactate increases in the blood has generally been expressed in terms of the individual's $\dot{V}O_2$ max. This may range from 40 - 45% of $\dot{V}O_2$ max. in the unfit individual (34) to 80% of $\dot{V}O_2$ max. or greater in the fit individual (23, 24). Closer scrutiny of the data of Wasserman et al. (131) and Williams et al. (137) showed that the difference between the highest and lowest $\dot{V}O_2$ max. was approximately 40%, whereas the difference between the highest and lowest work rate, or %age of $\dot{V}O_2$ max. at which lactate began to accumulate in the blood was approximately 60%.

The above review has related to short-term work at various intensities of exercise (up to 8 - 10 minutes). If the work rate can be continued beyond 12 - 15 minutes, blood lactate levels begin to decrease (3, 13, 35, 71, 79, 96, 110, 114, 130, 131) and in very prolonged exercise, blood lactate levels return to near resting

values (8, 22, 23, 24, 74, 80). It has been shown that this is due to lactate being metabolized at various sites in the body (72, 107). Contrary to the accepted theory that a major portion of lactate is resynthesized to glycogen after exercise (98, 107), it has been shown that the major fate of lactate is oxidation (16, 66).

It has been generally accepted that the increase in blood lactate is due to a relative lack of oxygen supply to the working muscles (130, 131). This concept was challenged by Huckabee (67) whose ideas were in direct conflict with the concept of an anaerobic threshold (130). Huckabee's concept of 'excess lactate' and its direct relationship with oxygen debt has been refuted by subsequent research (83, 84, 99, 109). Stainsby and Barclay (124) have recently cited evidence against the concept that lactate is produced in muscles because of insufficient oxygen available to maintain electron transport in the mitochondria. Evidence suggests that electron transport is inadequate somewhere between the cytoplasm and mitochondrial NAD. Electrons do accumulate in the cytoplasm which contributes to lactate production, but oxygen is not the rate limiting metabolite.

It has been shown that the threshold of anaerobic metabolism is lower for work on the bicycle ergometer than on a step test or treadmill (79, 116, 117). This has been attributed to the particular recruitment of fast and slow twitch fibers, or the relative amount of muscle mass involved in the work performance. There is

a greater amount of isometric work in bicycle exercise and greater impairment of muscle blood flow with greater relative stress on one muscle group (the quadriceps) and less time for relaxation (79). Kay and Shephard (79) discussed the importance of interpreting lactate data properly, since it is influenced by timing and site of sample collection, duration of exercise and the method of expressing results. This has been indicated in recent work by Hirche et al. (62, 63), Karlsson (73, 74) and Knuttgen and Saltin (85) where it was shown that a considerable gradient exists between muscle lactate and blood lactate during exercise. Hirche et al. (63) showed that the permeation rate of lactate out of the muscle cell is influenced considerably by the pH level of the blood. During alkalosis, the lactic acid permeation rate was approximately three times the rate during acidosis. It appears that the muscle cell membrane is the main barrier to lactic acid diffusion out of muscle tissue (62). Knuttgen and Saltin noted that caution must be observed in arriving at conclusions concerning muscle metabolic events from observations of blood lactate changes.

CHAPTER III

METHODS AND PROCEDURES

Selection of Subjects

Thirty male students (age range 19 to 31) volunteered for the study. The volunteers included physical education students of varying fitness levels, and members of the University of Alberta track team.

Orientation

Subjects reported to the laboratory for a preliminary session, at which time test procedures were explained and each individual was made familiar with the test apparatus. A predicted $\dot{V}O_2$ max. was determined on each subject from one 6 minute submaximal workload (11), to serve as a rough guide in measuring the observed $\dot{V}O_2$ max. The subjects were asked to maintain their current physical activity patterns and diets and were instructed to not smoke (10) or engage in heavy physical activity at least two hours prior to a testing session. All of the testing was completed within a period of eight weeks.

Laboratory Tests

The subjects were tested in a laboratory maintained at a temperature of 20-21^{o}C but which was not humidity controlled. Barometric pressure and temperature were recorded periodically throughout a testing session.

Calibration of Apparatus

Bicycle ergometer - A mechanically braked Monark bicycle ergometer was utilized for the work tests and was calibrated with standard kilogram weights.

CO_2, O_2 and N_2 calibration gases - The test gases for calibration of the CO_2 and O_2 analyzers were analyzed with the micro-Scholander apparatus.

Godart capnograph and Beckman E-2 oxygen analyzers - The two analyzers were calibrated four or five times on each testing day. The capnograph was checked using CO_2 - free air and a known percentage of CO_2, and the Beckman was checked using room air and 0% oxygen (N_2 gas) as the two reference points.

Parkinson-Cowan volumeter - Various volumes (up to 150 litres) were checked against a tissot apparatus constructed at the University of Alberta. The volumeter had a constant error of approximately one liter over a wide range of values which was accounted for in the calculations.

Measurement of VO_2 max.

The VO_2 max. for each subject was determined on the Monark bicycle ergometer following the 'levelling-off' procedure of Astrand (5) as modified by Macnab et al. (87).

Prior to the test, the subject was weighed on a medical scale and connected to E.C.G. leads. The initial work-load was chosen depending on the size and activity level of each subject and on

the results of the predicted $\dot{V}O_2$ max. test. For all subjects, the initial work-load began with the pendulum set at 2 kp., and in some cases at 3 kp. Pedalling rate was maintained at 60 r.p.m. with the aid of a metronome. Each work-bout lasted for four minutes separated by a five minute rest. Each work-load was increased by 1 kp. up to a work-load that the subject could just maintain for four minutes. A further work-load was then attempted (by most subjects), in which the resistance was raised by ½ kp. only. Pedal revolutions were monitored for accurate determination of work-load and was accomplished by connecting an electric counter in series with the micro-switch on the ergometer and a Gralab timer. Heart rate was monitored by a portable Sanborn E.C.G.

Expired air from the subject was collected via a Collins triple J valve connected to a Douglas bag (previously checked for leaks) by a short length of low-resistance, flexicoil plastic hose. At submaximal work-loads expired air was collected between the third and fourth minute. At maximal work-loads the subject signalled to indicate when approximately one more minute could be maintained, at which time the expired air was collected. The mixed contents of the Douglas bag were analyzed during each rest period for percent CO_2, O_2 and for volume. $\dot{V}O_2$ (in l/min. and ml/kg/min.) was calculated with the aid of a computer program designed for the Olivetti programma 101 (135).

Measurement of Maximal Aerobic Capacity (MAC)

MAC was measured on a Monark bicycle ergometer from a modification of the procedure developed by Wasserman et al. (133). After weighing, measurements of $\dot{V}O_2$, ventilation and venous lactate were determined at each work-load; the latter two variables being used to determine the subject's MAC.

Each subject performed five or six work-loads at a pedal rate of 60 r.p.m., lasting for four minutes each and separated by a three minute rest. For each subject, the initial work load was determined by taking 20 or 30% of the maximal work-load. Choice of either depended upon the particular subject's fitness level. Each of the remaining work-loads was incremented by ½ kp. The amount of work accomplished at each level was accurately determined as previously described and heart rate was taken every two minutes. Collection of expired air, and the calculation of $\dot{V}O_2$ was performed as previously described for the $\dot{V}O_2$ max. test.

Blood samples were taken at rest and immediately following each work-load, by a registered technician. Samples were taken from the brachial or cubital vein of either arm. From previous pilot studies with five subjects, there had been little difficulty in obtaining six to seven samples of blood by the above method. In the present study, it was not possible to obtain this many samples from every subject. The time in which a sufficient amount of blood could be collected varied considerably and the procedure was uncomfortable for some of the subjects.

The protocol for determining the MAC had to be modified.

Modified Procedure for Determining the MAC

Each subject performed six consecutive work-loads (at 60 r.p.m.), lasting four minutes each. At the end of each four minutes, the work-load was incremented by ½ kp. Douglas bags (previously checked for leaks), were arranged in two banks of three for the collection of expired air. Analysis of expired air was left until the end of the work-bout (24 minutes), and was always completed within 45 minutes of the start of the test. The collection of expired air and the determination of work-load, heart rate, $\dot{V}O_2$, etc., were carried out as previously described.

Blood samples were taken at rest and between the third and fourth minute of each work-load (at the same time that expired air was collected). The blood samples were taken using a 21 guage catheter (intermittent vein infusion set) inserted into a superficial hand vein (40). Application of the catheter was carried out by a registered nurse. Coagulation of blood in the tubing (8.9 cm. in length) and the needle (1.9 cm.) was prevented by using a solution of heparin and normal saline [1 ml. heparin (1:1000) in 500 ml. normal saline]. After each blood sample was taken, 1 ml. of this solution was injected into the catheter which was drawn off before a new blood sample was taken. Blood samples were then analyzed for lactate concentration by the Sigma kit method (122).

Calculation of MAC

The MAC for each subject (Appendix E) was determined by plotting the measurements of pulmonary ventilation (l/min.) and lactate (mg%) against work-load. The work-load below which ventilation and/or lactate became non-linear with increasing rate of work (133), was taken as the subject's MAC, as illustrated in Figure 1. Because the changes in linearity of the ventilation and lactate curves did not always correspond at the same work-load (in less than half the cases), the MAC of each subject was determined from the ventilation and lactate curves separately [MAC (Ve) and MAC (Lv)].

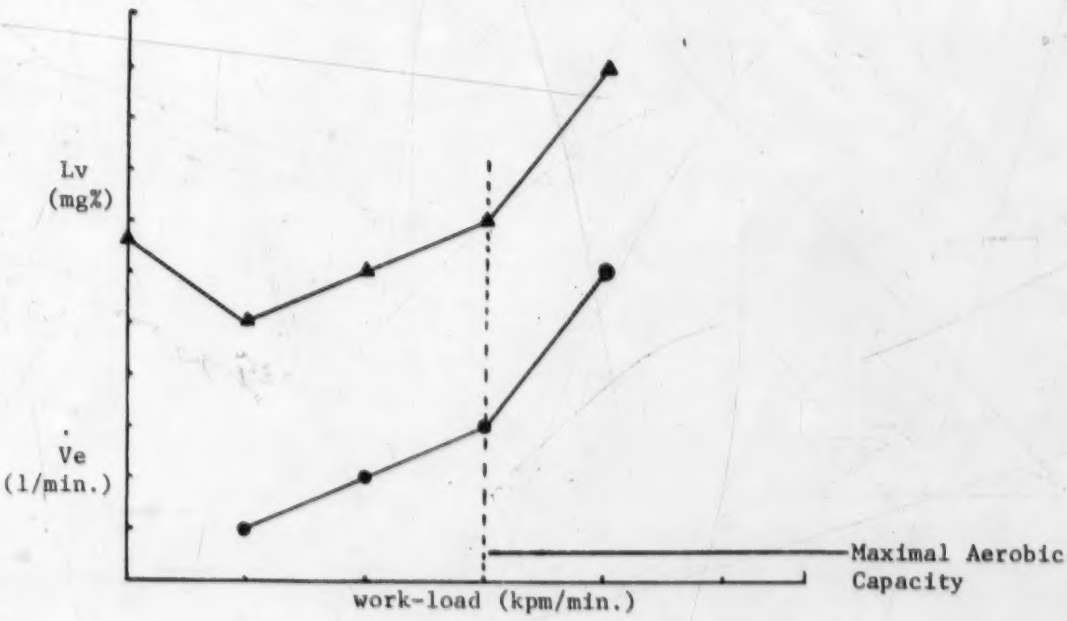

Figure 1. Illustration of the determination of maximal aerobic capacity as indicated by the non-linear increase in Ve and Lv with increasing work-load.

Endurance Tests

The twelve and thirty minute run-walks were performed on the University 440 yard track. Whenever possible subjects ran in groups of two or three, but in some instances it was necessary that a subject run alone. To facilitate measurement, the track was divided into eleven segments of forty yards each. Subjects were instructed to cover the greatest distance possible in the time period allotted by maintaining as even a pace as possible, without sprinting at the end of the run. Subjects lined up at the starting line (the end of segment 11) and on command proceeded to cover the greatest distance possible in the time allotted. The time was recorded with a stop-watch and lap times were given to each subject. A whistle was used to terminate the run and the total distance covered by each subject was then recorded (in yards). The values were then converted to meters.

Statistical Analysis

The absolute values for the $\dot{V}O_2$ max. and the MAC (Ve and Lv) were transformed to relative values as shown below:

1. $\dot{V}O_2$ max. (l/min.) - to ml/kg/min.,
2. MAC (Ve and Lv) -
   (a) $\dot{V}O_2$ (l/min.) - to ml/kg/min.,
   (b) $\dot{V}O_2$ (l/min.) - as a percentage of $\dot{V}O_2$ max.,
   (c) Work-load (kpm/min.) - as work-load/$\dot{V}O_2$ max. (47), and
   (d) Average heart rate at MAC - to percent of maximal heart rate (24).

Different relative values of the MAC were used to determine which value correlated best with the endurance run scores, and, therefore, produced the least residual variation in predicting endurance performance.

The t-test (for dependent samples) was used to test for significant differences between the MAC (Ve) and MAC (Lv). The t-tests were performed on both the absolute and relative values (Appendix A).

A correlation matrix was calculated on all the relevant variables measured in the four tests, employing the IBM 360 computer at the University of Alberta (Appendix C). It was then determined which method, i.e., the MAC (Ve) or MAC (Lv) correlated better with the remaining variables in the matrix. If the t-tests showed no significant differences between MAC (Ve) and MAC (Lv), only that method which correlated higher with the endurance run scores etc. was used in further analyses.

The relative measure of the MAC (Ve) or MAC (Lv) which correlated best with the endurance run scores was then determined. These correlations were compared for significant differences (dependent samples) against the correlations between the $\dot{V}O_2$ max. (ml/kg/min.) and the endurance run scores. The correlations between the endurance runs in relation to the $\dot{V}O_2$ max. and MAC were compared also for significant differences (Appendix B).

CHAPTER IV

RESULTS AND DISCUSSION

Characteristics of the Sample

A total of twenty six subjects completed the four tests in this investigation. The age range of the subjects was 19-31 years, and levels of activity varied from relatively sedentary individuals to well trained endurance athletes. The subjects included three distance runners and two sprinters from the University of Alberta track and field team, individuals involved in sports activities such as volleyball and hockey and a number of individuals who engaged in regular exercise. A few subjects took no regular exercise or participated in regular sports activities. For the data analysis, the subjects were not strictly classified into groups in terms of fitness level (for example, on the $\dot{V}O_2$ max. measurement). The means and standard deviations for age, height and weight are shown in Table I.

Discussion

The major purpose in selecting subjects involved in various levels of activity and training was to determine the extent of the variability present within the four tests of work or endurance capacity. The range of values for the MAC test have been shown to be much greater than for the $\dot{V}O_2$ max. test as measured in the same subjects (131, 137).

Due to the nature of the tests and the time period involved, it was, at times, difficult to secure subjects and maintain testing

TABLE I

MEANS AND STANDARD DEVIATIONS

FOR AGE, HEIGHT, AND WEIGHT

No.	Age	Height (Cm.)	Weight (kg.)
26	23.3	176.35	74.81
	±5.9	±6.52	±9.26

TABLE II

MEANS AND STANDARD DEVIATIONS OF THE

RELEVANT VARIABLES FROM THE $\dot{V}O_2$ max. TEST

No.	Weight (kg.)	W.L. max. (kpm/min.)	Heart Rate max.	$\dot{V}O_2$max. (l/min.)	$\dot{V}O_2$max. (ml/kg/min.)
26	74.81	1731.08	184.88	3.79	50.84
	±9.26	±230.46	±8.27	±0.51	±5.95

schedules. This was particularly the case during the period when the endurance runs were completed. Reliance had to be made also, on good weather conditions. Strict control over activity patterns and diet throughout the testing period was not possible, however subjects were requested to adhere, as closely as possible, to the instructions given prior to the commencement of the tests.

Relative Variation

In the present investigation, the intra-subject variability in each of the four tests was of interest due to the choice of subjects in which there was an extensive range in activity levels. A useful procedure for comparing the range or variation in a set of scores with that of another set of scores is the coefficient of variation (C.V.), ie. the standard deviation divided by the mean. This simply measures the magnitude of the variation relative to the size of a particular measurement. The standard deviation is expressed as a percentage of the mean, and therefore different variables may be compared more clearly in these terms (41).

Results of the $\dot{V}O_2$ max. test

The means and standard deviations of the relevant variables measured from the $\dot{V}O_2$ max. test are shown in Table II. In absolute terms the mean $\dot{V}O_2$ max. was 3.79 $\pm$ 0.51 l/min. (range 3.06 to 4.93, C.V. = 13.5%). In relative terms, the mean $\dot{V}O_2$ max. was 50.8 $\pm$ 5.9 ml/kg/min. (range 40.5 to 64.5, C.V. = 11.7%).

Following the criterion for determining the $\dot{V}O_2$ max., as outlined by Astrand (5), it was found that the $\dot{V}O_2$ max. 'levelled off'

(or declined slightly) with increasing work-load in 14 of the 26 subjects. Where this criterion was not met, the subjects in question felt unable to attempt a further work-load.

Discussion

Since the $\dot{V}O_2$ max. was measured on the bicycle ergometer, comparison with running performance may, perhaps, be questioned. It has been shown repeatedly that the $\dot{V}O_2$ max. measured on the inclined treadmill is some 7 to 12% greater than when measured on the bicycle ergometer, on the same sample of subjects (45, 60, 100). This is, however, an average value and Hermansen (60) has shown recently that the individual variation between the two tests is large, with a not always systematic difference between the two modes of exercise. The differences in oxygen uptake during maximal treadmill and bicycle exercise varied between plus 18.7 to minus 3.9%. Hermansen also found that the variation was not related to the state of training of the subject, previous experience in maximal exercise tests or to previous training in bicycling, which is in contrast to other reports in the literature (100, 116). Hermansen also found that haemodynamic responses such as pulmonary ventilation, blood lactate concentration, a-v oxygen difference and peripheral resistance were not significantly different between the two modes of exercise. The generally greater oxygen uptake for treadmill exercise was due to a greater heart rate and stroke volume and thus, cardiac output. The author concluded that there is not always a systematic difference in $\dot{V}O_2$ max. between the treadmill and bicycle ergometer, the difference (on the average)

is small, and either mode of exercise may be recommended for determination of the $\dot{V}O_2$ max. Since none of the subjects in the present investigation had extensive bicycling experience (except one - but also a distance runner), any possible bias (100) in the $\dot{V}O_2$ max. results when compared to the endurance performances was not deemed to be significant.

It is well known that in any sample of subjects tested, the intragroup variability for the $\dot{V}O_2$ max. measurement is substantial (60). In the present investigation the C.V. for the $\dot{V}O_2$ max. was 11.7% (Table VIII), similar to results reported in the literature (76, 77, 82). The large intragroup variability may, in large part, be explained by heredity (10, 60) and to some degree by level of physical activity, since training somewhat reduces the variation (46, 60, 75, 137).

A number of arbitrary criteria have been proposed to ensure that the $\dot{V}O_2$ max. has been reached (30). In young subjects, the primary criterion has generally been the establishment of a plateau in oxygen consumption despite further increases in work-load. The plateau, however, is not always demonstrable, no matter what the mode of exercise (30). In the present study, only 14 of the 26 subjects were able to demonstrate a plateau in oxygen consumption, following the criterion proposed by Astrand (5). Where this criterion was not met, the subjects felt unable to attempt a further work-load. The difficulty in demonstrating a plateau of oxygen consumption, particularly on the bicycle ergometer, has been attributed to a greater localized fatigue in the working

musculature compared to the more general fatigue experienced during a treadmill test (45, 60). More than one plateau has been demonstrated by Glassford et al. (45) when using the treadmill, after the criterion of Taylor et al. (125) had been met. Cumming and Borysyk (30) have stated that theoretically, the plateau phenomenon is exact, but is much less so in practise. A more practical approach for determining the $\dot{V}O_2$ max. was proposed by the authors.

The MAC Test

The plots of the ventilation (Ve) and lactate (Lv) measurements in relation to the six work-loads (for each subject) may be seen in Appendix E. The changes in linearity of Ve and Lv with increasing work-load did not always occur at the same point and therefore, the MAC (work-load in kpm/min.) was determined from the ventilation - MAC (Ve) and lactate - MAC (Lv) curves separately. This was done to determine if there was a significant difference in the MAC values between the two methods.

Results of the MAC Test - MAC (Ve) vs. MAC (Lv)

Once the MAC (Ve and Lv) had been determined for each subject, the first two work-loads below and above the MAC were selected. The means and standard deviations for work-load, lactate and ventilation for the five work levels [for MAC (Ve) and MAC (Lv)], are shown in Table III. The raw data for the five work-loads is depicted in Appendix D for each method.

TABLE III

MEANS AND STANDARD DEVIATIONS OF WORK-LOAD, LACTATE AND VENTILATION FOR FIVE WORK LEVELS IN DETERMINING MAC (Ve) AND MAC (Lv)

	Work-Load (kpm/min.)		Lactate (mg.%)		Ventilation (liters/min.)	
			Rest 14.6 ±4.7			
	Ve	Lv	Ve	Lv	Ve	Lv
W.L. 2	491.5	470.0	10.9	10.4	37.0	35.9
below MAC	±281.5	±285.6	±4.0	±4.1	±12.2	±11.1
No.	23	19	23	19	23	19
W.L. 1	632.4	574.8	13.1	11.8	43.4	39.9
below MAC	±293.6	±286.9	±7.2	±4.4	±14.3	±12.3
No.	26	26	26	26	26	26
W.L. at	810.8	754.0	16.7	12.9	51.0	49.0
MAC	±290.7	±282.5	±7.4	±4.7	±15.9	±13.9
No.	26	26	26	26	26	26
W.L. 1	994.7	935.8	23.7	22.7	66.7	60.3
above MAC	±292.3	±281.8	±9.3	±7.1	±19.0	±16.8
No.	26	26	26	26	26	26
W.L. 2	1157.9	1105.3	36.0	31.2	78.6	73.5
above MAC	±290.1	±285.9	±11.9	±8.0	±21.5	±17.0
No.	25	24	25	24	24	24

The mean MAC (Ve) was 810 $\pm$ 290.7 kpm/min. (C.V. = 36%) compared to the mean of 754.0 $\pm$ 282.5 kpm/min. (C.V. = 37.5%) for the MAC (Lv). The difference of 56.8 kpm/min. was not significant ($t = 1.993$, $p > 0.05$ - see Appendix A). The correlation (Figure 2) between the two methods of determining the work-load at MAC was 0.87 ($p < 0.01$). The correlation was determined using a standard program designed for the Olivetti programma 101.

Relative Values of the MAC (Ve and Lv)

The absolute values of work-load, $\dot{V}O_2$ and average heart rate at the MAC were transformed into relative values. The respective absolute values became work-load/$\dot{V}O_2$ max., $\dot{V}O_2$ (ml/kg/min.), $\dot{V}O_2$ (% of $\dot{V}O_2$ max.) and heart rate (% of H.R. max.). The four measures were utilized to determine the best method of expressing the MAC in relation to the endurance performances.

The means and standard deviations of the absolute and relative values for MAC (Ve and Lv), at the level of the MAC, are presented in Table IV. The associated values (X's $\pm$ S.D.'s) for lactate and ventilation are also presented. The means of the relative values for MAC (Ve) were slightly greater compared to the respective values for the MAC (Lv). However, t-tests (for dependent samples) performed on each pair indicated no significant differences at the 0.05 level of significance (Appendix A).

The coefficient of variation for the relative MAC (average value for the four measures - both methods) was approximately twice that for the relative measure of $\dot{V}O_2$ max. (Table VIII).

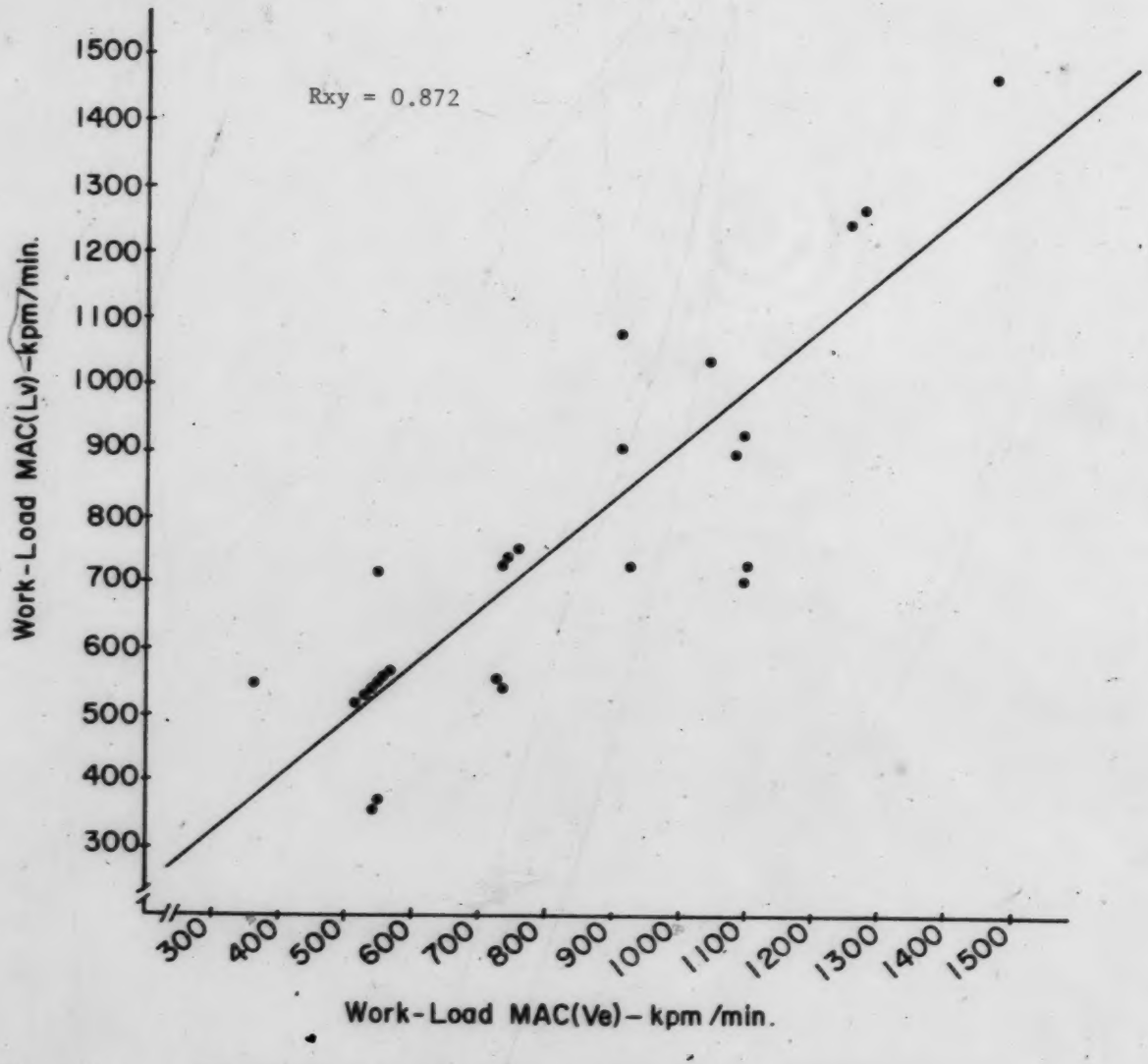

Figure 2. RELATIONSHIP OF MAC (Ve) WITH MAC (Lv) - ABSOLUTE WORK-LOADS

TABLE IV

MEANS AND STANDARD DEVIATIONS OF THE RELEVANT

VARIABLES ASSOCIATED WITH THE MAC -

FOR MAC (Ve) AND MAC (Lv)

	Wt. (kg.)	W.L. (kpm/min.)	W.L. / VO2 max.	VO2 (l/min.)	VO2 (%of VO2 max.)	VO2 (ml/kg/min.)	Ave. H.R.	H.R. (%of H.R.max.)	Lv (mg%)	Ve (l/min.)
MAC (Ve)	74.3	810.8	209.5	1.98	51.3	26.7	129.3	70.3	16.8	51.0
N = 26	±9.2	±290.7	±52.0	±0.62	±10.9	± 8.1	±18.1	±10.4	±7.4	±15.9
MAC (Lv)	74.3	754.0	195.2	1.88	48.8	25.3	124.7	67.7	12.9	49.0
N = 26	±9.2	±282.5	±53.5	±0.59	±11.1	±7.7	±17.7	±9.9	±4.7	±14.0

Discussion

No significant differences were found between the MAC (Ve) and MAC (Lv) - (absolute and relative values) and the correlation (Figure 2) between the two methods (work-load in kpm/min.) was substantial ($r = 0.87$, $p < 0.01$). Davis (58) reported a higher correlation of 0.95. The results from the present study and those of Davis confirm the findings of Wasserman et al. (133) that there is a close relationship between changes in lactate and changes in ventilation during an incremental work test to detect the anaerobic threshold. The less precise relationship between the MAC (Ve) and MAC (Lv) in the present study may be due, in part, to errors in measurement. A number of other factors are also possible.

One of these factors pertains to the blood sampling technique used (intermittent catheter). From the individual graphs (Appendix E), it is apparent that for some of the subjects, lactate values fluctuated considerably over the six work-loads. The lactate curve bore little relationship with the corresponding ventilation curve. The fluctuations in lactate values, in most cases, corresponded to tests where there was some difficulty in obtaining blood samples at the prescribed time. In these cases, the subject was required to pedal beyond the four minute period at a particular work-load. The lactate values could also have been influenced if the subject shifted weight or changed the alignment of his legs to the pedals during the work bout (13). In the cases where the lactate values seemed haphazard (in relation to the work-loads), repeat analyses were made, giving the same results.

A second factor responsible for the slight discrepancy between the MAC (Ve) and MAC (Lv) may have been due to the procedure by which the MAC was determined from the lactate curves. In almost all cases, lactate values for the first two or three work-loads were below the resting value. For consistency in method, the MAC was chosen at the point below which the lactate curve became non-linear with increasing work-load. In some cases this occurred when the lactate values were still below the resting value. Determining the MAC from the ventilation curves presented little difficulty. In 12 cases ventilation changes did not follow lactate changes. Therefore, there was little correspondence between the two curves, particularly below the work-loads determined as the MAC. In 9 of the 12 subjects in which there was a non-correspondence between the curves, the MAC (Lv) was lower than the MAC (Ve). Of the nine, seven were one work-load below the MAC (Ve) and the other 2 were two work-loads below. In 3 cases the MAC (Lv) was determined one work-load above the MAC (Ve). Because the MAC (Lv) was below the MAC (Ve) in nine of the subjects, it might be argued that this was due to a delayed response of ventilation to the increase in lactate and hence CO_2. However, the work periods were of four minutes duration, and Davis (38) and Wasserman et al. (133), have shown a strong relationship between changes in ventilation and lactate values from work tests in which each work-load lasted only one minute.

It may be concluded that the main reason for the discrepancy between the MAC (Ve) and MAC (Lv) in absolute or relative terms, was because of the procedure used to determine the MAC from the lactate curves. The procedure was used to maintain consistency.

The average variability in the relative values of the MAC (Ve) and MAC (Lv) was considerable, with a C.V. of approximately 22%. The C.V. for the absolute work-load (both methods) was approximately 36%. For the MAC (Ve), the difference between the highest and lowest work-load at the MAC was 75% (range 360 to 1470 kpm/min.), similar to the results of Wasserman et al. (131) on a group of untrained subjects 23 to 31 years of age and Wasserman et al. (133) on 85 normal subjects 17-91 years of age. In a study by Williams et al. (137) on a group of young Bantu subjects, the difference between the highest and lowest % of $\dot{V}O_2$ max. at which lactate increased above resting values was 52%, which was reduced to 41% after training.

Results of the Twelve and Thirty Minute Run-Walks

The means, standard deviations, ranges and C.V.'s for both endurance performances are shown in Table V. The variability in performance was slightly greater in the thirty minute run (C.V. = 13.4%) compared to the twelve minute run (C.V. = 12.2%). The correlation between the two runs (Figure 3) was 0.93 ($p<0.01$).

In both endurance performances, subjects maintained a running pace throughout, except in the thirty minute run, where two of the subjects were forced, periodically, to reduce their pace to a walk. In both performances, a few subjects were inclined to sprint near the end of each time limit.

Discussion

Difficulties were encountered in maintaining schedules for

TABLE V

MEANS, STANDARD DEVIATIONS, RANGE AND COEFFICIENTS OF VARIATION FOR THE TWELVE AND THIRTY MINUTE RUN-WALKS

N = 26	Mean	S.D.	Range	C.V.(%)
		±		
12. min. Run-Walk (Meters)	2917.3	357.0	2448 to 3748	12.2
30 min. Run-Walk (Meters)	6485.9	865.9	5274 to 8456	13.4

Rxy = 0.925

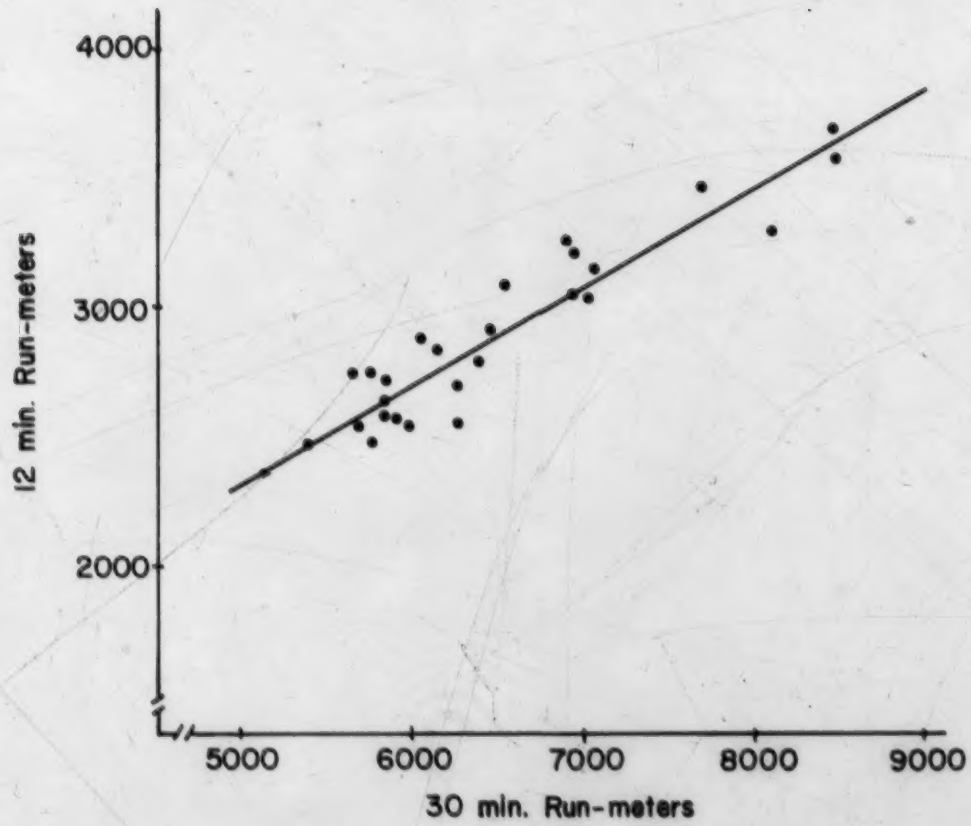

Figure 3. RELATIONSHIP OF THE THIRTY MINUTE RUN WITH THE TWELVE MINUTE RUN

the endurance runs, due, mainly to inclement weather. In most instances, subjects ran in groups of two or three, but this was not always possible. Lap times were given so that the subjects had some 'lee-way' in adjusting their pace throughout each performance. Even though time remaining was known to each subject, very few attempted, or were able, to sprint at the end of each run.

The C.V. for the twelve minute run was 12.2%. For similar distances (subjects untrained and of similar age) the C.V. (approximately 8%) is slightly less (77, 82, 121). The variability increases when the age range is greater (76). In untrained subjects the variation between the scores increases as the length or duration of the run increases (77). However, for highly trained athletes (24) the variability in the performance of a 10 mile run is similar to the variability for a two mile run in untrained subjects. This may be due to the ability of endurance athletes to utilize a large percentage of their $\dot{V}O_2$ max.; the differences in this ability being less than for a group of untrained subjects. The overall spread in scores for the thirty minute run (C.V. = 13.4%) was similar to that for the twelve minute run (C.V. = 12.2%).

Correlations

Results of the Relative Measures of $\dot{V}O_2$ max., the MAC (Ve and Lv) and the Twelve and Thirty Minute Run-Walks

A correlation matrix on 18 variables measured from the four tests was computed and may be seen in Appendix C. For comparison,

the correlations of most interest were those between the relative measures of $\dot{V}O_2$ max., the MAC (Ve and Lv) and the twelve and thirty minute run-walks. A correlation maxtrix on these variables may be seen in Table VI.

Since there were no significant differences between the MAC (Ve) and MAC (Lv) expressed in absolute or relative terms, no tests for significant differences between the relevant correlations using the relative measures of the MAC (Lv) were warranted. As may be seen from Table VI, the relative measures of MAC (Ve) formed the best relationships with the $\dot{V}O_2$ max. and the endurance runs, and the results were dealt with using the relative measures of the MAC (Ve) only. Of the four relative measures of the MAC (Ve), the MAC expressed as $\dot{V}O_2$ (ml/kg/min.) formed the best relationship with the other variables (Table VI and Appendix C). The correlations between the MAC (Ve) - $\dot{V}O_2$ (ml/kg/min.) and the endurance runs were then compared with the correlations between the $\dot{V}O_2$ max. (ml/kg/min.) and the endurance runs. The correlations between the two endurance runs in relation to the $\dot{V}O_2$ max. and MAC were also compared.

The twelve minute run-walk had a correlation of 0.77 ($p < 0.01$) with the MAC (Figure 4) compared to a correlation of 0.76 ($p < 0.01$) with the $\dot{V}O_2$ max (Figure 5). The difference was not significant ($p > 0.05$, Appendix B). The correlation between the thirty minute run-walk and the MAC (Figure 6) was 0.72 ($p < 0.01$) compared to a correlation of 0.67 ($p < 0.01$) with the $\dot{V}O_2$ max. (Figure 7). This difference was also not significant ($p > 0.05$, Appendix B).

TABLE VI

CORRELATION MATRIX ON THE RELATIVE MEASURES OF VO_2 max., THE MAC (Ve and Lv) AND THE TWELVE AND THIRTY MINUTE RUN-WALKS

* **		VO2 max. (ml/kg/min.)	VO2 (MAC) (ml/kg/min.)	VO2 (MAC) (%of VO2max.)	W.L.(MAC) / VO2max.	H.R.(MAC) (% of max.)	12 Min. Run	30 Min. Run
VO2max. (ml/kg/min.)	Ve	-						
	Lv	-						
VO2(MAC) (ml/kg.min.)	Ve	.82	-					
	Lv	.72	-					
VO2(MAC) (%of VO2max.)	Ve	.63	.95	-				
	Lv	.43	.92	-				
W.L.(MAC) / VO2max.	Ve	.73	.96	.95	-			
	Lv	.53	.95	.96	-			
H.R.(MAC) (%of max.)	Ve	.60	.83	.86	.85			
	Lv	.45	.84	.90	.83			
12 min. Run	Ve	.76	.77	.66	.75	.57	-	
	Lv	.76	.69	.51	.60	.45	-	
30 min. Run	Ve	.67	.72	.63	.71	.51	.93	-
	Lv	.67	.65	.47	.56	.38	.93	-

* A correlation of .388 is required for significance at the 0.05 level.

** A correlation of .496 is required for significance at the 0.01 level.

$Y = 33.843X + 2015.257$

$Se_y = 228.84$

$Rxy = 0.767$

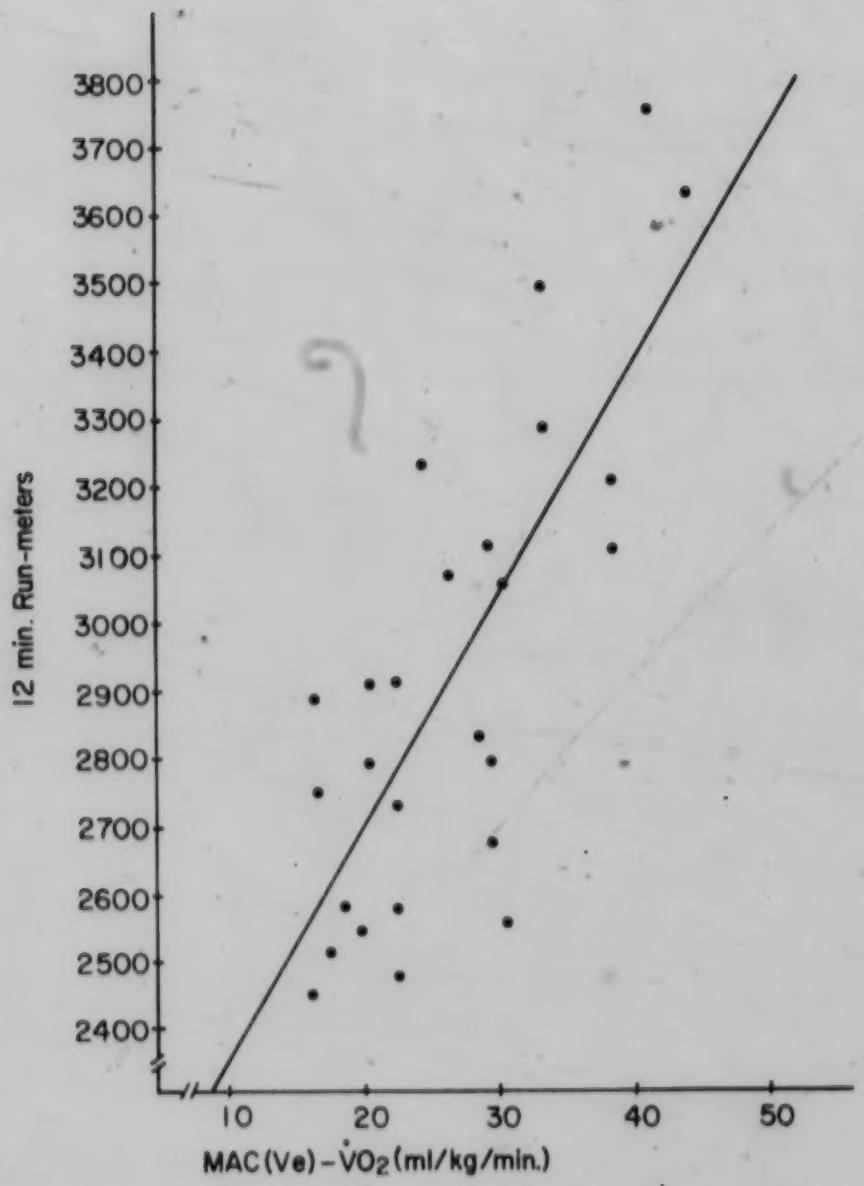

Figure 4. RELATIONSHIP OF THE MAC (Ve) - $\dot{V}O_2$ (ml/kg/min.) WITH THE TWELVE MINUTE RUN

$Y = 45.369X + 610.793$

$Se_y = 233.56$

$Rxy = 0.756$

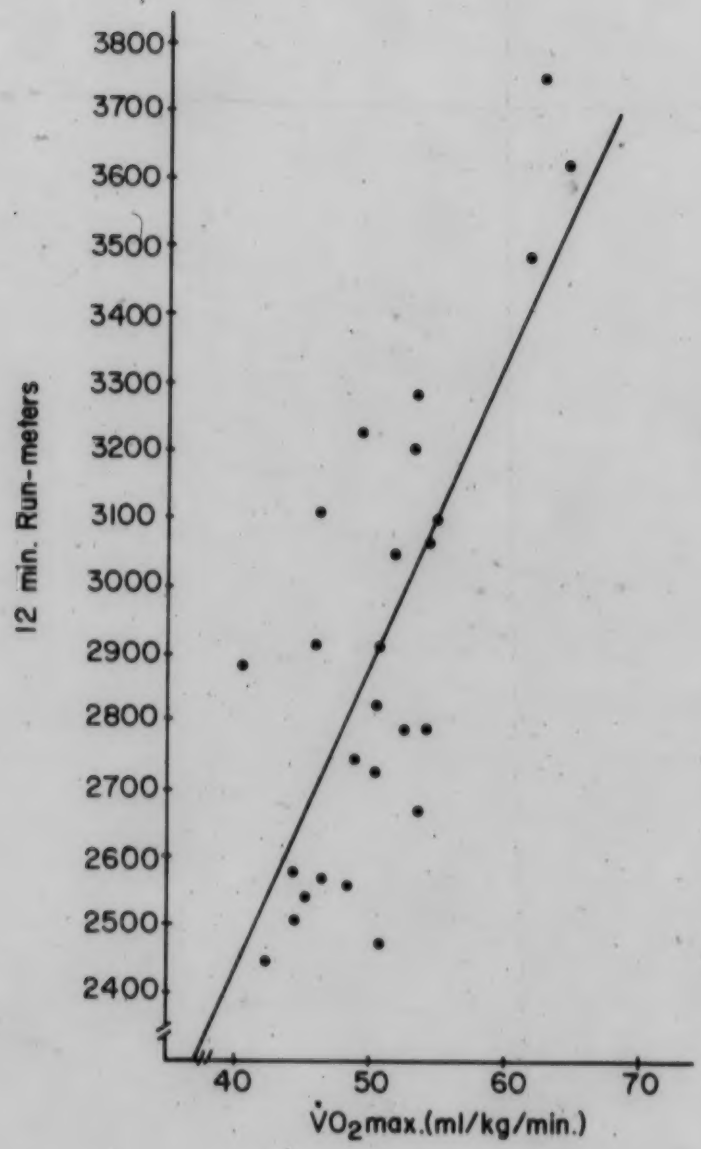

Figure 5. RELATIONSHIP OF THE $\dot{V}O_2$ max. (ml/kg/min.) WITH THE TWELVE MINUTE RUN

$Y = 77.271X + 4426.38$

$Se_y = 599.13$

$Rxy = 0.722$

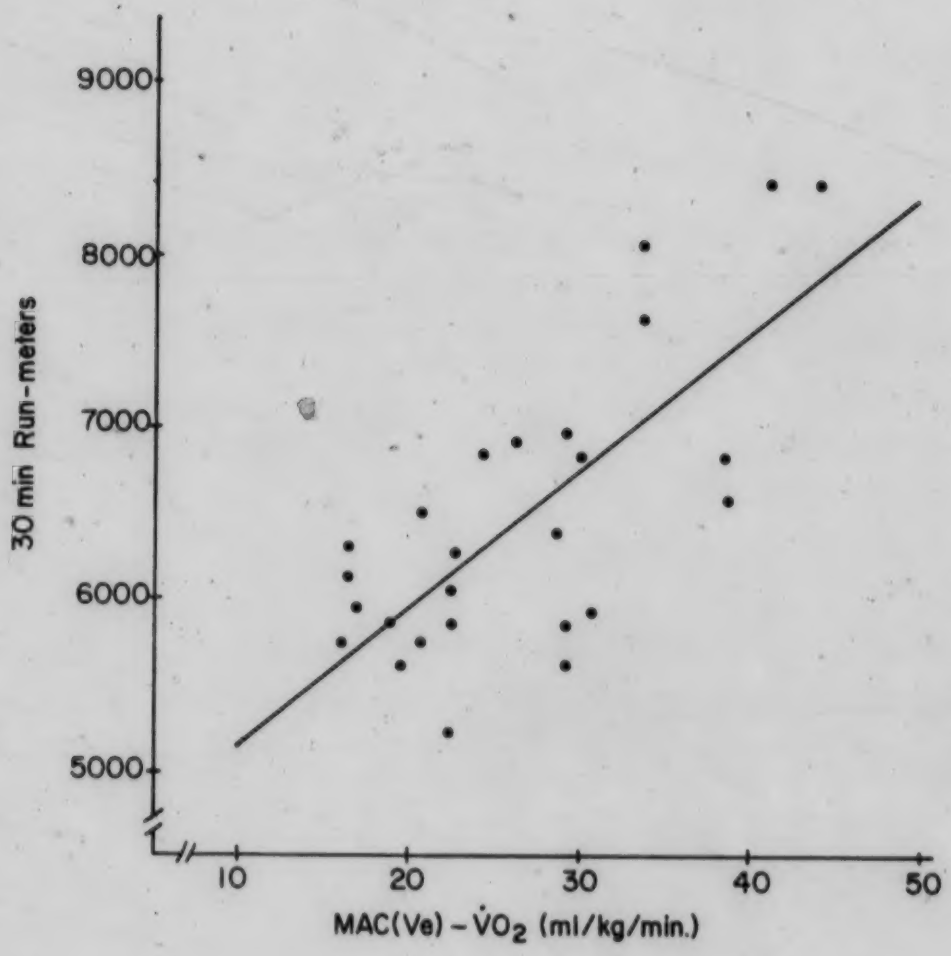

Figure 6. RELATIONSHIP OF THE MAC (Ve) - $\dot{V}O_2$ (ml/kg/min.) WITH THE THIRTY MINUTE RUN

$Y = 98.252X + 1490.93$

$Se_y = 638.88$

$Rxy = 0.675$

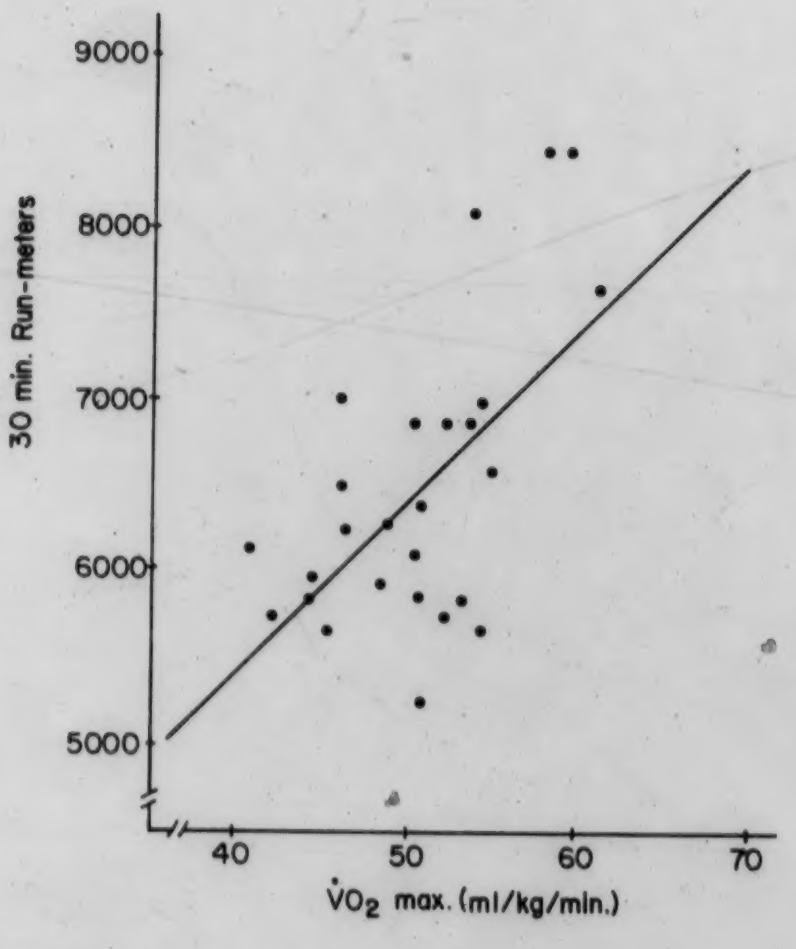

Figure 7. RELATIONSHIP OF THE $\dot{V}O_2$ max. (ml/kg/min.) WITH THE THIRTY MINUTE RUN

The correlation between the MAC and the twelve minute run-walk was 0.77 ($p < 0.01$) compared to a correlation of 0.72 ($p < 0.01$) with the thirty minute run-walk. The difference was not significant ($p > 0.05$, Appendix B). The correlation between the $\dot{V}O_2$ max. and the twelve minute run-walk was 0.76 ($p < 0.01$) compared to a correlation of 0.67 ($p < 0.01$) with the thirty minute run. The difference also was not significant ($p > 0.05$, Appendix B).

The standard errors (Se) in predicting the twelve and thirty minute run-walks from knowledge of the individual's $\dot{V}O_2$ max. and MAC were calculated. The results for the relative $\dot{V}O_2$max. and the four relative measures of the MAC (Ve) are shown in Table VII. The least error in predicting both running performances was gained from a knowledge of the individual's MAC, expressed as $\dot{V}O_2$ (ml/kg/min.).

The correlation between $\dot{V}O_2$ max. (ml/kg/min.) and MAC (Ve) [$\dot{V}O_2$ (ml/kg/min.)] (Figure 8) was 0.82 ($p < 0.01$). The correlation between relative $\dot{V}O_2$ max. and body weight ($r = -0.34$) was not significant ($p > 0.05$, Appendix C). Similarly, the correlation between MAC (Ve) [$\dot{V}O_2$ (ml/kg/min.)] and body weight ($r = -0.09$) was not significant ($p > 0.05$, Appendix C). The correlations between body weight and the twelve and thirty minute run-walks were, respectively, -0.18 and -0.05 ($p > 0.05$, Appendix C).

Discussion

The $\dot{V}O_2$ max. and Running Performance

Running performances of 12 to 20 minutes (untrained subjects) have been shown to relate best to the $\dot{V}O_2$ max. (ml/kg/min.) as

TABLE VII

STANDARD ERROR IN PREDICTING THE TWELVE AND THIRTY MINUTE RUN-WALKS FROM THE RELATIVE MEASURES OF $\dot{V}O_2$ MAX. AND THE MAC (Ve)

	Standard Error - In Meters				
		MAC (Ve)			
	$\dot{V}O_2$max. (ml/kg/min.)	$\dot{V}O_2$ (ml/kg/min.)	$\dot{V}O_2$ (%of $\dot{V}O_2$max.)	W.L. $\dot{V}O_2$max.	H.R. (%of H.R.max.)
12 min. Run	233.56	228.84	266.62	236.52	318.70
30 min. Run	638.88	599.13	675.25	607.19	815.01

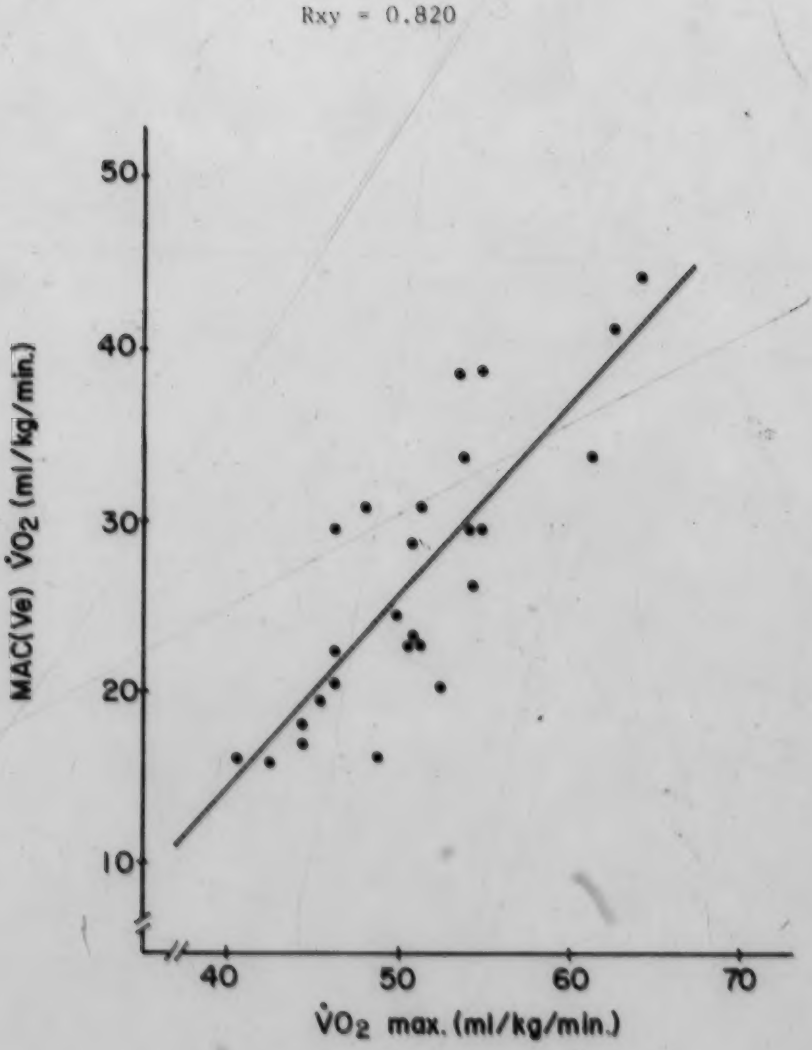

Figure 8. RELATIONSHIP OF THE MAC (Ve) - $\dot{V}O_2$ (ml/kg/min.) WITH THE $\dot{V}O_2$ max. (ml/kg/min.)

opposed to runs of shorter or longer duration (12). This was confirmed in the present investigation. The $\dot{V}O_2$ max. correlated 0.76 with the twelve minute run-walk compared to a correlation of 0.67 with the thirty minute run-walk. The difference, however, was not significant. Possible reasons for the difference in the correlations are discussed later.

Generally, time to cover two miles, or distance covered in twelve minutes have been the endurance tasks used in correlational analyses with the $\dot{V}O_2$ max. In studies (76, 77, 121) where the $\dot{V}O_2$ max. was determined on the bicycle ergometer, correlations of 0.59, -0.55 and -0.34 have been reported. In studies where the treadmill was used to measure the $\dot{V}O_2$ max. (untrained subjects), correlations with endurance performance have ranged from 0.65 to 0.90 (19, 86). In the present investigation, the correlation of 0.76 was substantial compared to the majority of studies just mentioned. This may have been due, in part, to the particular selection of subjects.

In a study of world-class marathon runners, Costill et al. (23) reported a correlation of -0.08 between the $\dot{V}O_2$ max. (treadmill) and time for a marathon run. In contrast, Costill et al. (24) found a correlation of -0.91 between the $\dot{V}O_2$ max. (treadmill) and the time for a ten mile run (endurance athletes).

Explanations for the variation in the correlations between the different studies are not readily apparent. For untrained subjects the generally low correlations may be explained by individual differences in motivation, tolerance to pain or individual differ-

ences in strength (77). Also possible is an inability to utilize a high percentage of the $\dot{V}O_2$ max. (35). This does not explain the results of Cooper (19) in which a correlation of 0.90 was found between $\dot{V}O_2$ max. and distance covered in a twelve minute run-walk. The spurious factor of age (76) may have influenced the results (age range 17-54). The relatively high correlation of 0.76 in the present study may have been due to the wide range in fitness levels. Motivational factors etc. should not be a problem for highly trained endurance athletes, and since endurance athletes are able to utilize a very high percentage of their $\dot{V}O_2$ max. (23, 24, 35), one would expect a high correlation between running performance and the $\dot{V}O_2$ max. This relationship was found (24) for a run of ten miles ($r = -0.91$) but not for a marathon run [$r = -0.08$ (23)]. Davies (35) has stated that the $\dot{V}O_2$ max. may be decisive in performances of up to 1 hour duration (the approximate time for a ten mile run for endurance athletes), after which the individual's maximal aerobic capacity becomes more important.

When endurance performance (bicycle ergometer) and $\dot{V}O_2$ max. are measured simultaneously, a spurious correlation may result between the two measures, because of the common element of time, and the significant relationship between body weight, the endurance performance and the oxygen uptake (76). Katch (76) has suggested that correlations between a physiological measure and an endurance performance are meaningful only if the tests are administered independently of each other.

The MAC and Running Performance

Almost identical correlations were found between the MAC (Ve) [$\dot{V}O_2$ (ml/kg/min.)] and the twelve and thirty minute run-walks (r = 0.77 and 0.72 respectively). To the author's knowledge, there has been no previous attempt to relate the MAC to some type of endurance performance, although Costill et al. (24) approached this area of study from a different aspect on a group of highly trained endurance athletes. Responses of $\dot{V}O_2$ (expressed as % of $\dot{V}O_2$ max.) and heart rate (expressed as % of H.R. max.) were measured on a treadmill at a rate of 268 meter/min. The respective values correlated -0.94 and -0.98 with a ten mile run for time. The average % of $\dot{V}O_2$ max. on the treadmill was 78% and during the ten mile run was 86% (91% when an estimate of air resistance was added). The precise MAC was not determined on each athlete. Therefore, it is not known how closely the responses on the treadmill (at 268 meters/min.) matched the MAC's of the athletes. However, for the fastest runners, lactate values remained near resting and increased with the slower runners. At all running speeds above 70% of $\dot{V}O_2$ max., the faster runners accumulated less blood lactate than the slower runners at similar speeds and relative percentages of their aerobic capacities.

Wasserman et al. (131) showed that a work-load just below the anaerobic threshold (the MAC) could be performed for 50 minutes, whereas work-loads above this level resulted in performance decrement before the 50 minute time limit.

Davies and Harris (33) compared the PDI (as determined from the pulse-deficit of exercise) with the $\dot{V}O_2$ max. In addition, three standard indices of work capacity were compared with the $\dot{V}O_2$ max. It was found that the PDI^{65} (analogous to the MAC) correlated best (r= 0.86) with the $\dot{V}O_2$ max.^{65} compared to the other indices of work capacity. In the present study, the MAC (Ve) [$\dot{V}O_2$ (ml/kg/min.)] correlated 0.82 with the $\dot{V}O_2$ max. (Figure 8).

MAC and $\dot{V}O_2$ max. in Relation to Endurance Performance

The MAC failed to predict the twelve and thirty minute run-walks significantly better than the $\dot{V}O_2$ max. The correlations between the MAC (Ve) and the two endurance runs (twelve and thirty minute) were more similar (r = 0.77 and 0.72) than the corresponding correlations with the $\dot{V}O_2$ max. (r = 0.76 and 0.67). Although the latter two correlations were not significantly different, the $\dot{V}O_2$ max. predicted the thirty minute run with less precision than the twelve minute run. Even though the four correlations were significant ($p < 0.01$), only some 50% of the error in predicting the twelve and thirty minute run-walks is removed from a knowledge of the $\dot{V}O_2$ max. or MAC (44). Several reasons are possible why the MAC did not show a significantly greater correlation with the endurance runs compared to the $\dot{V}O_2$ max.

For subjects not trained in cycling, the AT (as% of $\dot{V}O_2$ max.) measured on the bicycle ergometer is generally lower than on the treadmill (79) although this appears not always to be the case (36).

It is possible, then, that there is not always a systematic difference in measurements of the AT between the two ergometers, as is true for the $\dot{V}O_2$ max. measurement (60). The discrepancies (if any) in the differences of the AT between the two modes of exercise may be due to the specificity of training (100). Or, the relative percentages of slow and fast twitch fibers in the relevant muscle groups (25, 39, 50, 51, 52, 53, 68, 102) may be a factor, and the particular way in which the fiber types are recruited during cycling and running. In addition, more of the leg musculature is utilized during running compared to cycling (60). It was assumed at the beginning of the study that factors such as these would not unduly influence the results of the tests performed on the bicycle ergometer, since none of the subjects were trained in cycling (except one). Additional reasons were given for choosing the bicycle ergometer over the treadmill.

The endurance runs used in the investigation may not have been long enough in order to show a significant difference between the correlations with the MAC and $\dot{V}O_2$ max. It is interesting to note that for the twelve minute run, the correlations between the $\dot{V}O_2$ max. and MAC were identical. For the thirty minute run, the MAC correlated slightly better than did the $\dot{V}O_2$ max. The MAC also correlated more consistently with the two runs, than did the $\dot{V}O_2$ max. It is not known how these relationships would hold compared to a run of longer duration. In the study by Costill et al. (23) on marathon runners, there was no relationship between the $\dot{V}O_2$ max. and a marathon run for time

($r = -0.08$). In a later study, Costill et al. (24) showed that there is a strong relationship between the $\dot{V}O_2$ max. and time for a ten mile run ($r = -0.91$). Submaximal responses of $\dot{V}O_2$ and heart rate (expressed as percentages of maximal) on the treadmill (268 meters/min.) showed somewhat higher correlations. These individual responses may have been close to the MAC of each athlete (especially for the faster runners). The results of the two studies by Costill et al. lend proof to Davies' (35) hypothesis that the $\dot{V}O_2$ max. is an important determiner of endurance work for periods up to one hour beyond which the aerobic capacity may be more decisive. From the results of the present study it may only be stated that Davies' hypothesis tends to be supported.

Relative Measures of the MAC

Davis (36) has found that the most meaningful way to express the AT (and hence the MAC) is as a percentage of the $\dot{V}O_2$ max. However, in the present study, it was found that the $\dot{V}O_2$ expressed as ml/kg/min. formed the best correlations with the $\dot{V}O_2$ max. and the endurance runs. Work-load/$\dot{V}O_2$ max. (47) was nearly as accurate as $\dot{V}O_2$ (ml/kg/min.) - Table VII. The reason is probably due to greater precision in measurement ie. work-load and body weight may be accurately measured. A further relative measure of MAC (which was not initially considered in the study) is work-load/body weight. This measure was calculated for MAC (Ve) and correlated with the $\dot{V}O_2$ max. and the twelve and thirty minute run-walks. The respective correlations were 0.86, 0.81 and 0.77 ($p < 0.01$). However, the correla-

tions between the $\dot{V}O_2$ max. and the MAC (Ve) as work-load/body weight with respect to the endurance runs remained non-significant. The correlations between the two endurance runs in relation to the MAC (Ve) as work-load/body weight also remained non-significant (Appendix B).

General Discussion

The measure of relative variation (C.V.) was used in the present study to generally compare the extent of the variability within each of the four tests (Table VIII). A distribution of the scores for each test is shown in Figure 9. The large C.V. for the MAC (Ve) compared to the other three tests is reflected in the distributions. The MAC scores are more clearly separated, and the resolution of the scores for the $\dot{V}O_2$ max. and the endurance runs are much less distinct. The three endurance athletes and one of the sprinters are clearly distinguished in the thirty minute run and the same four subjects are in the top six scores on the MAC test (also clearly distinguished). The $\dot{V}O_2$ max. and twelve minute run tests separate clearly only three of the four best runners. The poorest runner in both endurance performances is in eighth position from the bottom on the MAC test and in twelfth position from the bottom on the $\dot{V}O_2$ max. test. Davies and Harris (33) found that the PDI^{65} classified fitness levels more clearly than two other standard indices of work capacity ie., the work $capacity_{170}$ and the Leistungpulseindex.

The MAC appears to indicate a clearer separation of fitness levels compared to the $\dot{V}O_2$ max. and the endurance runs. The intra-group variability in $\dot{V}O_2$ max. scores is primarily due to heredity

TABLE VIII

COEFFICIENTS OF VARIATION ON THE RELATIVE MEASURES OF VO_2 max., THE TWELVE AND THIRTY MINUTE RUN-WALKS AND THE MAC (Ve and Lv)

C.V. in Percent										
			MAC (Ve and Lv)							
VO2max. (ml/kg/min.)	12 min. Run	30 min. Run	VO2 (ml/kg/min.)		VO2 (%of VO2max.)		W.L. VO2max.		H.R. (%H.R.max.)	
			Ve	Lv	Ve	Lv	Ve	Lv	Ve	Lv
11.7	12.2	13.4	30.4	30.4	21.2	22.8	24.8	27.4	14.8	14.6

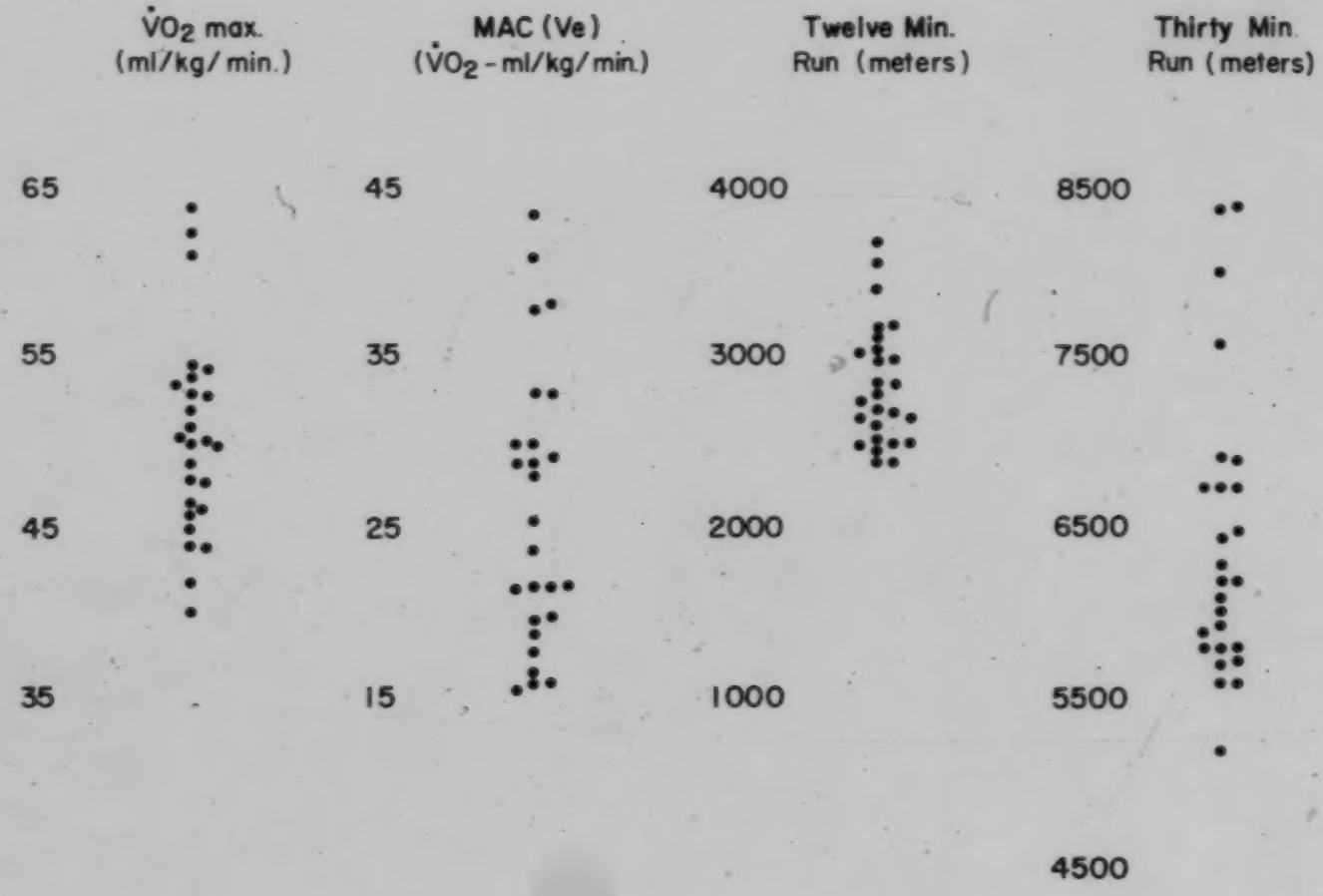

Figure 9. DISTRIBUTION OF SCORES FOR THE $\dot{V}O_2$ max. (ml/kg/min.), MAC (Ve) - $\dot{V}O_2$ (ml/kg/min.) AND THE TWELVE AND THIRTY MINUTE RUN-WALKS

and somewhat to activity level (60). The MAC may be more related to activity level, or state of training. Davies (34) has stated that the PDI^{65} is primarily dependent on fitness level and relatively independent of sex and age. Fitness level, however, is related to sex and age when the $\dot{V}O_2$ max. is used as the criterion of fitness. Although $\dot{V}O_2$ max. declines with age, occupational work capacity (percentage of maximal) remains relatively undiminished to the age of 70 years (115).

Over the years a number of studies have been carried out to determine the optimum intensity of work (usually expressed as a percentage of $\dot{V}O_2$ max.) for different periods of time. For eight hours of work, intensities ranging from 20 to 40% of maximal have been recommended (115). I. Astrand (quoted in references 10 and 115) found that labourers (self-paced), on the average, worked at 40% of their $\dot{V}O_2$ max. However, an average value is not particularly useful since some individuals are able to work at a greater percentage of maximal than others. It is possible that an individual works at a rate that is closely related to his MAC, particularly for an extended period of time. Simonson (123) has stated that prolonged performance is possible only at work rates below the level at which ventilation rate increases out of proportion to the increase in work-load. Wasserman et al. (131) have supported this view as indicated by the results of their study. In relation to this, when work is continued for a prolonged period, blood lactate levels remain at or close to the resting value (8, 22, 23, 24, 74, 80).

The results of the present study (at least for the subjects studied in this investigation) indicate that the MAC test may be widely applied in the various areas of fitness evaluation. The test has a number of apparent advantages:

1. The test is submaximal (safety) and may be easily administered.
2. The MAC is a direct measurement, ie. no extrapolation is necessary.
3. It is not necessary to take $\dot{V}O_2$ measurements since the MAC may be accurately expressed as work-load/body weight.
4. It appears that the MAC may be determined by using measurements of ventilation (liters/min.) at each work-load, without necessitating blood sampling.
5. Reliance does not have to be made on heart rate, which may be altered by factors other than the external work-load.
6. The MAC test appears to separate out levels of fitness more discriminantly than the $\dot{V}O_2$ max. test.
7. The MAC test appears to be as good as the $\dot{V}O_2$ max. test in predicting twelve minute run performance and slightly better when predicting thirty minute run performance, and
8. The bicycle ergometer appears to be an adequate apparatus to use in measuring the MAC in relation to running performance.

Hyperventilation may be a potential problem when determining the MAC, however, others have shown that this is rarely the case (133).

Since ventilation rate at each work-load is a critical measurement, a rapid and precise method of measuring this variable is necessary to obtain accurate results.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The objectives of the present investigation were:

1. To verify the relationship between changes in blood lactate and changes in ventilation during an incremental work test to determine the MAC,
2. (a) To correlate the twelve minute run-walk with the MAC and the $\dot{V}O_2$ max. and test for a significant difference between the two correlations,

   (b) To correlate the thirty minute run-walk with the MAC and the $\dot{V}O_2$ max. and test for a significant difference between the two correlations,
3. To test for significant differences between:

   (a) the correlations of the twelve and thirty minute run-walks with the MAC,

   (b) the correlations of the twelve and thirty minute run-walks with the $\dot{V}O_2$ max., and
4. To generally compare the coefficients of variation (standard deviation/mean) of the four tests.

A total of 30 subjects (19-31 years of age) volunteered for the study and 26 individuals completed the four tests. Activity levels ranged from relatively sedentary individuals to highly trained endurance athletes.

The $\dot{V}O_2$ max. was measured on a Monark bicycle ergometer employing the 'levelling-off' criterion of Astrand (6) as modified by Macnab et al. (87). The Douglas bag technique was used to determine the $\dot{V}O_2$ values.

The MAC was initially determined by a discontinuous incremental work test in which blood samples (up to 7) were taken from the brachial or cubital vein. It proved impossible to obtain this number of blood samples from all subjects by this method and the procedure had to be modified.

The new procedure was carried out by determining the MAC from an incremental continuous work test (133). Work-loads (at 60 r.p.m.) began at 20 or 30% of $\dot{V}O_2$ max. (depending on the size and fitness status of the individual) and were incremented 1/2 kp. every four minutes. Expired air was collected into Douglas bags between the third and fourth minute at each work-load (total of six) and analyzed for CO_2 and O_2 concentration and for volume upon completion of the test (24 minutes duration). Blood samples (including a resting sample) were obtained (from a catheter inserted into a superficial hand vein) at the same time that expired air was collected at each work-load. Blood samples were subsequently analyzed for lactate concentration by the Sigma kit procedure.

The twelve and thirty minute run-walks were performed on an outdoor 440 yard track. Each subject was instructed to pace himself in order to cover the greatest distance possible in the allotted time. Distances were recorded in yards and converted to meters.

Ventilation (liters/min) and blood lactate (mg%) responses from

the MAC test were plotted against work-load for each subject. The MAC was then determined from the ventilation [MAC (Ve)] and lactate [MAC (Lv)] curves separately. The absolute values of the MAC (work-load, $\dot{V}O_2$ and heart-rate) from each method were converted to relative values to determine the most appropriate method of expressing the MAC.

The results indicated no significant differences between the MAC (Ve) and MAC (Lv) in both absolute and relative terms. The work-loads at MAC (Ve) and MAC (Lv) showed a correlation of 0,87 ($p < 0,01$) confirming reports in the literature that there is a strong relationship between changes in ventilation and changes in blood lactate during an incremental work test to determine the AT (and hence the MAC).

The absolute and relative values of the MAC (Ve) formed better correlations with the $\dot{V}O_2$ max. and the twelve and thirty minute run-walks compared to the values for the MAC (Lv). Values for the MAC (Ve) only were used in subsequent analysis. Of the four relative values of the MAC (Ve), the $\dot{V}O_2$ expressed in ml/kg/min. formed the best correlations with the endurance runs and $\dot{V}O_2$ max. Consequently, this form of the variable was used in the comparisons with the $\dot{V}O_2$ max. (ml/kg/min.).

The twelve minute run-walk correlated 0,77 ($p < 0,01$) with the MAC and 0,76 ($p < 0,01$) with the $\dot{V}O_2$ max. The two correlations were not significantly different. The thirty minute run-walk correlated 0,72 ($p < 0,01$) with the MAC and 0,67 ($p < 0,01$) with the $\dot{V}O_2$ max. and the two correlations were not significantly different.

The twelve and thirty minute run-walks correlated 0.77 and 0.76 ($p < 0.01$) respectively with the MAC and were not significantly different. The twelve and thirty minute run-walks correlated 0.76 and 0.67 ($p < 0.01$) respectively with the $\dot{V}O_2$ max. and again were not significantly different.

The MAC was found to be a slightly better predictor of endurance performance compared to the $\dot{V}O_2$ max., particularly with regard to the thirty minute run-walk. The correlations, however, were not particularly high. Only some 50% of the error in predicting the endurance runs could be eliminated from a knowledge of the individual's $\dot{V}O_2$ max. or MAC.

The $\dot{V}O_2$ max. (ml/kg/min.) and the MAC (ml/kg/min.) correlated 0.82. The twelve and thirty minute run-walks had a correlation of 0.93.

The C.V. for each test was calculated and compared. The C.V. for the MAC (Ve) expressed as $\dot{V}O_2$ (ml/kg/min.) was twice that for the $\dot{V}O_2$ max. and endurance run results. A graphic distribution of the results from each test showed that the MAC had a much greater range of scores, and scores were more distinctly separated in contrast to the other three tests.

A relative measure of the MAC not originally considered in the study was work-load/body weight. This variable was calculated for the MAC (Ve) and correlated with the $\dot{V}O_2$ max. and the two endurance runs. Slightly higher correlations were determined; due, most likely, to the greater accuracy in measuring work-load and body weight.

Conclusions

In terms of the subjects studied in this investigation, the MAC test appears to be at least as good in predicting endurance performance

of twelve minutes duration compared to the $\dot{V}O_2$ max., and slightly better when predicting an endurance run of thirty minutes duration. It is apparent also that the MAC separates out levels of fitness more clearly than does the $\dot{V}O_2$ max. The MAC value is a direct measurement (no extrapolation is necessary) which does not rely on heart rate measurements. It appears that blood sampling is not necessary to determine the MAC, which may be accomplished from measurements of ventilation rate alone. With refinement in technique, the MAC test had wide application in the various areas of fitness evaluation.

Recommendations

Previous research (38, 133) and the results of the present investigation have shown that departure from linearity of ventilation rate during an incremental work test corresponds very closely to an increase in blood lactate above the resting value. There is some discrepancy however, especially in the results of the present investigation. The discrepancies were most likely due to errors in measurement and in using the Douglas bag technique to measure ventilation rate. Instrumentation is required such that ventilation rate may be measured continuously and recorded while the test is in progress. It should be possible to design a simplified measuring and recording system such that the departure from linearity of ventilation rate with increasing work-load may be seen visually as the test progresses. This system has been used by others (38, 97, 133) but with sophisticated and expensive apparatus. The advantages of such a recording system are that the test procedure may be considerably shortened (one minute for each

work-load) and the test may be terminated soon after the disproportionate increase in ventilation rate has been seen visually on the recording paper.

It is recommended that further research be conducted (using suitable instrumentation) to ascertain the most suitable increments in work-load to detect increases in blood lactate above the resting level and the corresponding disproportionate increase in ventilation rate. Some question still remains as to how much blood lactate should be above the resting value before the MAC work load is determined. Similarly, how great a departure from linearity of ventilation rate should there be before the MAC is determined? Further information on these questions would make the test more definitive.

Additional research is required in which the treadmill is utilized to determine the MAC and the $\dot{V}O_2$ max. in comparison to measurements determined on the bicycle ergometer. These responses should be related to endurance performance (run-walking) of one to two hours duration.

The relationship between the MAC and endurance performance should be studied in various homogeneous groups (in terms of age, sex and fitness level) to ascertain the generalizability and applicability of the MAC test.

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APPENDIX A

t-TESTS FOR SIGNIFICANT DIFFERENCES ON THE ABSOLUTE AND RELATIVE VALUES BETWEEN MAC(Ve) AND MAC(Lv)

APPENDIX A

t-Tests for Dependent Samples (44)

The test statistic for dependent samples is given by:

$$t = \frac{\bar{d}}{\frac{S_d}{\sqrt{n}}}$$

where

$\bar{d}$ is the average of the n difference scores, S_d is the standard deviation of the n difference scores, and n is the number of pairs of observations.

Tests for Significant Differences

The t-tests were performed to test for significant differences between the MAC(Ve) and MAC(Lv) on both the absolute and relative values at the 0.05 level of confidence.

Summary Table	MAC(Ve) vs. MAC(Lv)			
Tests	$\bar{d}$	S_d	$\pm$ .975 t 25	p*
1. Work-load (kpm/min.)	56.85	144.96	1.993	>0.05
2. $\dot{V}O_2$ (ml/kg/min.)	1.48	4.54	1.664	>0.05
3. $\dot{V}O_2$ (% of $\dot{V}O_2$ max.)	2.42	9.07	1.360	>0.05
4. Work-load/$\dot{V}O_2$ max.	14.24	38.77	1.874	>0.05

* t of 2.060 required for significance at the 0.05 level of confidence

APPENDIX B

TESTS FOR SIGNIFICANT DIFFERENCES BETWEEN r_{xy} AND r_{xz} ON THE VO_2 max., MAC(Ve) AND THE TWELVE AND THIRTY MINUTE RUN-WALKS

APPENDIX B

Tests for Significant Differences Between r_{xy} and r_{xz} Using Dependent Samples

The test statistic is given by (44):

$$z = \frac{\sqrt{n}\,(r_{xy} - r_{xz})}{\sqrt{(1-r^2_{xy})^2 + (1-r^2_{xz})^2 - 2r^3_{yz} - (2r_{yz} - r_{xy}r_{xz})(1 - r^2_{xy} - r^2_{xz} - r^2_{yz})}}$$

where

the value of z is compared with the 100 (α/2) and 100 [1 - (α/2)] percentile points in the unit normal distribution, n is the sample size and r_{xy} is the sample correlation between x and y, r_{xz} is the sample correlation between x and z, and r_{yz} is the sample correlation between y and z.

The following z tests were calculated at the 0.05 level of confidence.

	Correlated Variables	r
1. a.	MAC(Ve) - $\dot{V}O_2$ (ml/kg/min.) vs. 12 min run	.77
b.	MAC(Ve) - Work-Load/wt. vs. 12 min. run	.81
c.	$\dot{V}O_2$ max. (ml/kg/min.) vs. 12 min. run	.76
2. a.	MAC(Ve) - $\dot{V}O_2$ (ml/kg/min.) vs. 30 min. run	.72
b.	MAC(Ve) - Work-Load/wt. vs. 30 min. run	.77
c.	$\dot{V}O_2$max. (ml/kg/min.) vs. 30 min. run	.67

APPENDIX B (con't)

		r
3. a.	12 min. run vs. $\dot{V}O_2$ max. (ml/kg/min.)	.76
b.	30 min. run vs. $\dot{V}O_2$ max. (ml/kg/min.)	.67
c.	12 min. run vs. MAC(Ve) - $\dot{V}O_2$ (ml/kg/min.)	.77
d.	30 min. run vs. MAC(Ve) - $\dot{V}O_2$ (ml/kg/min.)	.72
e.	12 min. run vs. MAC(Ve) - Work-Load/wt.	.81
f.	30 min. run vs. MAC(Ve) - Work-Load/wt.	.77

Summary Table

Tests	Correlations		Diff.	z	p*
1. a vs. c	.77	.76	0.01	0.141	>0.05
b vs. c	.81	.76	0.05	0.807	>0.05
2. a vs. c	.72	.67	0.05	0.612	>0.05
b vs. c	.77	.67	0.10	1.371	>0.05
3. a vs. b	.76	.67	0.09	1.649	>0.05
c vs. d	.77	.72	0.05	1.012	>0.05
e vs. f	.81	.77	0.04	0.891	>0.05

* z of 1.96 required for significance at the 0.05 level of confidence

APPENDIX C

CORRELATION MATRIX ON THE RELEVANT VARIABLES MEASURED FROM THE $\dot{V}O_2max.$, MAC(Ve) AND MAC(Lv) AND THE TWELVE AND THIRTY MINUTE RUN-WALK TESTS

TABLE IX

CORRELATION MATRIX ON THE RELEVANT VARIABLES MEASURED FROM THE $\dot{V}O_2$ max., MAC AND THE TWELVE AND THIRTY MINUTE RUN-WALKS

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Ve^{o} Lv^{oo}	1	Ht. (cm.)	-																	
	2	Wt. (kg.)	.53	-																
			.53	-																
	3	W.L. max. (kpm/min.)	.36	.54	-															
			.36	.53	-															
	4	H.R. max. (b/min.)	-.46	-.54	-.51	-														
			-.46	-.54	-.51	-														
	5	VO2 max. (l/min.)	.41	.59	.88	-.44	-													
			.41	.59	.88	-.44	-													
	6	VO2 max. (ml/kg/min.)	-.05	-.34	.48	.05	.55	-												
			-.05	-.34	.48	.05	.55	-												
	7	12 min. Run (meters)	.25	-.20	.39	-.29	.47	.76	-											
			.25	-.20	.39	-.29	.47	.76	-											
	8	30 min. Run (meters)	.21	-.05	.48	-.37	.53	.67	.93	-										
			.21	-.05	.48	-.37	.53	.67	.93	-										
	9	W.L. (MAC) (kpm/min.)	.32	.27	.81	-.39	.87	.73	.69	.71	-									
			.29	.29	.79	-.35	.79	.62	.62	.62	-									
	10	VO2(MAC) (l/min.)	.33	.31	.81	-.45	.85	.66	.65	.65	.98	-								
			.31	.35	.81	-.41	.79	.56	.57	.57	.98	-								
	11	VO2(MAC) (%of VO2max.)	.23	.09	.63	-.37	.62	.63	.66	.63	.89	.94	-							
			.17	.13	.57	-.30	.48	.43	.51	.47	.87	.91	-							

*Correlation of 0.388 required for significance at 0.05 level.

**Correlation of 0.496 required for significance at 0.01 level.

^{o}Ve - Upper correlation in each row

^{oo}Lv - Lower correlation in each row

TABLE IX

CORRELATION MATRIX ON THE RELEVANT VARIABLES MEASURED FROM THE VO_2max., MAC AND THE TWELVE AND THIRTY MINUTE RUN-WALKS

Ve[o] Lv[oo]	* **	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
12	VO2 (MAC)	.12	-.06	.63	-.26	.65	.82	.77	.72	.92	.92	.95	-						
	(ml/kg/min.)	.09	-.03	.63	-.22	.59	.72	.69	.65	.93	.92	.92	-						
13	W.L. (MAC)	.25	.08	.68	-.32	.70	.73	.75	.71	.96	.94	.95	.96	-					
	VO2 max.	.19	.13	.61	-.27	.57	.53	.59	.56	.95	.93	.96	.95	-					
14	Ave. H.R.(MAC)	.02	-.13	.47	-.07	.45	.65	.51	.42	.73	.73	.80	.80	.81	-				
	(b/min.)	-.02	-.15	.38	.01	.29	.48	.38	.28	.69	.72	.84	.81	.79	-				
15	H.R. (MAC)	.16	.04	.59	-.36	.56	.59	.57	.51	.80	.82	.86	.83	.85	.95	-			
	(%of H.R.max.)	.12	.02	.53	-.28	.41	.45	.46	.38	.77	.82	.89	.84	.83	.95	-			
16	Lactate (MAC)	.16	-.06	-.16	-.07	.00	.07	.08	.07	.06	.12	.17	.14	.08	.28	.29	-		
	(mg%)	.33	.08	-.23	.02	-.10	-.18	-.08	-.08	-.22	-.25	-.31	-.32	-.27	-.21	-.22	-		
17	Vent.(MAC)	.26	.27	.72	-.41	.82	.67	.63	.63	.94	.96	.90	.91	.90	.75	.83	.26	-	
	(l/min.)	.23	.27	.70	-.33	.73	.58	.55	.54	.94	.96	.89	.91	.91	.76	.82	-.18	-	
18	Wt. (MAC)	.55	.98	.53	-.52	.60	-.31	-.18	-.05	.26	.29	.05	-.09	.06	-.12	.04	-.02	.25	-
	(kg.)	.55	.98	.53	-.52	.60	-.31	-.18	-.05	.27	.33	.10	-.06	.09	-.15	.02	.15	.24	-

*Correlation of 0.388 required for significance at 0.05 level

**Correlation of 0.496 required for significance at 0.01 level

[o]Ve - Upper correlation in each row

[oo]Lv - Lower correlation in each row

APPENDIX D

RAW DATA FROM THE $\dot{V}O_2$max. TEST, THE ENDURANCE RUN TESTS AND THE MAC TEST - MAC(Ve) AND MAC(Lv)

TABLE X

RAW DATA FROM THE $\dot{V}O_2$ max. TEST, THE TWELVE AND THIRTY MINUTE RUN-WALKS AND THE RESTING LACTATE FROM THE MAC TEST

S.	Age (yrs)	Ht. (cm.)	Wt. (kg.)	W.L. max. (kpm/min.)	H.R. max. (b/min.)	$\dot{V}O_2$max. (l/min.)	$\dot{V}O_2$max. (ml/kg/min.)	12 min. run (meters)	30 min. run (meters)	Rest Lactate (mg%)
A.B.	24	172	72.7	2187	184	4.69	64.5	3621.0	8456.4	8.0
R.C.	31	178	94.5	1952	180	4.39	46.5	2571.3	6217.9	11.5
P.C.	23	182	79.8	1665	180	4.03	50.6	2910.5	6085.3	22.0
V.C.	21	176	64.8	1658	187	3.41	52.6	2788.9	5732.4	10.5
D.F.	21	184	74.1	1506	184	3.66	49.4	3232.4	6814.1	16.0
B.G.	22	177	78.3	1800	173	4.16	53.2	3283.6	8091.5	12.5
S.G.	26	175	84.3	1841	180	3.76	44.6	2511.9	5992.9	24.0
L.G.	23	188	82.7	2070	173	3.82	46.2	3112.6	6997.0	7.5
D.H.	28	175	70.7	1435	195	3.13	44.3	2579.5	5842.1	14.0
D.Hr.	28	166	72.3	1566	173	3.33	46.0	2908.7	6502.3	14.0
C.H.	19	182	69.4	1953	184	4.28	61.7	3486.6	7649.9	11.5
B.H.	25	178	77.9	1793	195	4.23	54.2	2792.6	5664.7	16.0
J.J.	25	172	80.2	1640	200	3.92	48.9	2743.2	6282.8	14.5
H.K.	24	175	66.3	1613	187	3.62	54.6	3065.1	6974.1	8.5
T.K.	29	185	80.0	1464	180	3.24	40.5	2884.9	6115.5	14.5
J.L.	20	174	67.3	1566	200	3.41	50.7	2824.1	6322.2	20.5
D.Mc.	23	159	62.7	1647	195	3.20	50.9	2478.0	5274.3	9.0
T.M.	20	176	76.4	1446	187	3.23	42.3	2447.9	5779.0	18.5
V.M.	21	174	72.7	1710	180	3.86	53.1	3203.1	6814.1	16.0
D.M.	20	180	70.5	1988	180	4.43	62.8	3747.7	8452.7	8.5
G.M.	22	173	69.1	1695	191	3.59	51.9	3055.0	6814.1	19.5
D.N.	21	176	75.2	1830	180	4.14	55.0	3100.7	6554.4	16.0
F.P.	23	169	72.5	1551	187	3.27	45.1	2541.1	5607.1	23.0
R.P.	19	172	67.7	1620	191	3.64	53.7	2674.6	5847.6	16.0
A.S.	22	178	60.7	1507	191	3.06	50.3	2723.9	5843.9	16.5
D.S.	25	189	102.3	2305	170	4.93	48.2	2559.4	5906.1	11.5

TABLE XI

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE VENTILATION CURVES

1. RAW DATA FOR THE SECOND WORK-LOAD BELOW THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min.	H.R. 4 min.	H.R. Ave.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)	Wt. (kg)
A.B.	1089	2.35	50.2	33.1	232.0	115	114	115	62.5	12.0	55.4	71.1
R.C.	551	1.50	34.2	16.1	125.3	100	100	100	55.5	11.0	39.0	93.6
P.C.	357	1.09	26.9	13.2	88.5	92	93	93	51.6	8.5	38.4	82.3
V.C.												63.9
D.F.	374	1.14	31.0	15.4	102.1	97	83	90	48.9	10.5	31.0	73.6
B.G.	732	1.81	43.4	23.4	175.8	107	108	108	62.4	11.5	45.1	77.3
S.G.	185	0.93	24.7	11.1	49.1	87	95	91	50.6	10.0	26.2	83.9
L.G.	547	1.64	43.0	20.1	143.2	106	107	107	61.8	6.0	36.5	81.6
D.H.	185	0.72	22.9	10.5	59.1	92	90	91	46.7	7.5	23.0	68.6
D.H.												71.6
C.H.	726	1.87	43.8	24.9	169.5	141	136	139	75.6	17.0	49.2	75.0
B.H.	720	1.84	43.6	23.6	170.3	132	130	131	67.2	7.5	42.8	78.1
J.J.	189	0.93	23.6	11.4	48.1	87	92	90	45.0	8.5	30.0	81.4
H.K.	365	1.00	27.8	15.1	100.9	101	99	100	53.5	11.5	25.0	66.4
T.K.	183	0.77	23.9	9.6	56.5	79	89	84	46.7	21.0	25.7	80.9
J.L.	360	1.17	34.3	17.6	105.5	105	107	106	53.0	18.5	32.5	66.6
D.Mc.	182	0.70	21.9	11.1	56.9	92	95	94	48.2	5.5	18.2	63.2
T.M.												72.9
V.M.	729	1.97	50.9	27.9	188.7	129	129	129	71.7	10.5	51.7	70.6
D.M.	915	2.24	50.6	32.8	206.8	125	132	129	71.7	11.0	57.4	68.2
G.M.	563	1.47	40.9	21.7	156.8	127	120	124	64.9	5.0	33.1	67.8
D.N.	705	1.83	44.3	25.0	170.4	123	125	124	68.9	8.0	53.7	73.3
F.P.	183	0.84	25.7	11.7	55.9	105	111	108	57.8	10.5	24.1	71.8
R.P.	369	1.08	29.6	15.9	101.5	105	105	105	54.9	14.0	31.0	67.8
A.S.	176	0.88	28.6	14.5	57.6	118	118	118	61.8	13.0	25.4	60.5
D.S.	919	2.22	45.1	22.2	186.6	107	110	109	64.1	14.0	56.4	100.0

TABLE XI

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE VENTILATION CURVES

2. RAW DATA FOR THE FIRST WORK-LOAD BELOW THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min. H.R.	H.R. 4 min. H.R.	H.R. Ave. H.R.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)
A.B.	1297	2.85	60.6	40.0	276.4	136	136	136	73.9	9.5	67.4
R.C.	732	1.94	44.1	20.7	166.5	110	106	108	60.0	13.5	47.3
P.C.	524	1.38	34.2	16.8	129.9	101	95	98	54.0	10.0	37.7
V.C.	374	0.97	28.3	15.1	109.8	97	97	97	51.9	12.0	30.7
D.F.	572	1.61	44.0	21.9	156.2	98	105	102	55.4	9.5	40.1
B.G.	908	2.20	52.7	28.4	218.1	118	122	120	69.4	24.0	57.7
S.G.	365	1.21	32.2	14.4	96.9	102	102	102	56.7	10.5	31.2
L.G.	726	2.00	52.5	24.6	190.1	118	118	118	68.2	6.5	42.0
D.H.	366	0.98	31.4	14.3	116.9	102	103	103	52.8	8.0	29.6
D.Hr.	375	1.17	34.9	16.4	112.8	87	91	89	51.4	12.5	37.9
C.H.	926	2.36	55.0	31.4	216.3	150	150	150	81.5	21.0	62.9
B.H.	904	2.28	53.9	29.2	213.8	138	138	138	70.8	13.0	53.7
J.J.	362	1.03	26.2	12.6	92.3	94	98	96	48.0	13.5	30.0
H.K.	551	1.38	38.2	20.8	152.4	100	100	100	53.5	8.0	32.2
T.K.	366	1.04	32.1	12.9	113.0	100	105	103	57.2	23.5	31.5
J.L.	549	1.45	42.4	21.7	160.9	120	120	120	60.0	17.5	40.7
D.Mc.	365	1.06	33.1	16.8	114.1	107	113	110	56.4	5.5	23.6
T.M.	183	0.84	26.0	11.5	56.6	90	92	91	48.7	8.5	27.5
V.M.	904	2.32	60.1	32.9	234.0	141	138	140	77.8	8.5	60.9
D.M.	1094	2.54	57.4	37.2	247.2	138	138	138	76.7	9.5	62.9
G.M.	723	1.84	51.1	27.1	201.3	132	132	132	69.1	6.5	40.2
D.N.	908	2.27	54.8	30.9	219.4	136	141	139	77.2	38.0	68.6
F.P.	363	1.21	36.9	16.8	110.9	125	132	129	68.9	6.0	32.8
R.P.	549	1.55	42.7	22.9	150.9	111	114	113	59.2	16.0	47.6
A.S.	363	1.10	35.9	18.1	118.8	129	122	126	65.9	17.0	27.8
D.S.	1094	2.69	54.6	26.9	222.7	118	114	116	68.2	13.0	64.5

TABLE XI

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE VENTILATION CURVES

3. RAW DATA FOR THE WORK-LOAD AT THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min.	H.R. 4 min.	H.R. Ave.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)
A.B.	1470	3.14	66.9	44.1	313.2	145	148	147	79.9	8.5	81.5
R.C.	923	2.11	48.0	22.5	210.0	129	122	126	70.0	17.5	54.1
P.C.	726	1.85	45.8	22.5	180.0	110	111	111	61.7	13.0	44.9
V.C.	556	1.28	37.6	20.1	163.2	115	115	115	61.5	11.5	36.5
D.F.	741	1.82	49.6	24.7	202.3	111	113	112	60.9	11.5	48.3
B.G.	1098	2.58	62.0	33.4	263.7	136	136	136	78.6	28.0	68.0
S.G.	540	1.44	38.2	17.1	143.5	113	108	111	61.7	11.5	36.7
L.G.	911	2.39	62.5	29.2	238.5	129	127	128	73.9	7.0	50.8
D.H.	547	1.28	40.9	18.6	174.8	113	113	113	57.9	13.5	36.5
D.Hr.	560	1.48	43.9	20.6	168.4	113	111	112	64.7	15.0	42.1
C.H.	1094	2.50	58.4	33.3	255.5	161	164	163	88.6	30.0	68.1
B.H.	1040	2.30	54.3	29.4	245.9	148	150	149	76.4	13.5	60.5
J.J.	531	1.36	34.5	16.7	135.4	105	105	105	52.5	14.5	35.6
H.K.	729	1.74	48.1	26.2	201.6	115	113	114	60.9	12.5	43.2
T.K.	551	1.31	40.4	16.2	170.1	111	110	111	61.7	25.5	35.2
J.L.	729	1.90	55.8	28.6	213.6	138	134	136	68.0	23.0	48.9
D.Mc.	545	1.42	44.2	22.4	170.4	123	122	123	63.1	6.0	31.9
T.M.	360	1.17	36.1	16.0	111.4	103	98	101	54.0	21.0	32.9
V.M.	1080	2.73	70.5	38.6	279.6	155	153	154	85.6	19.5	69.0
D.M.	1276	2.82	63.7	41.3	288.4	143	148	146	81.1	13.0	67.9
G.M.	904	2.07	57.5	30.5	251.7	150	150	150	78.5	8.0	49.2
D.N.	1094	2.86	69.0	38.9	264.4	155	104	160	88.9	31.5	83.4
F.P.	545	1.43	43.6	19.9	166.6	145	141	143	76.5	13.5	41.7
R.P.	735	1.99	54.6	29.3	202.1	129	129	129	67.5	27.5	56.0
A.S.	542	1.34	43.8	22.2	177.4	136	129	133	69.6	25.0	30.0
D.S.	1255	3.07	62.4	30.7	254.8	132	134	133	78.2	14.5	73.1

TABLE XI

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE VENTILATION CURVES

4. RAW DATA FOR THE FIRST WORK-LOAD ABOVE THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min.	H.R. 4 min.	H.R. Ave.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)
A.B.	1634	3.56	75.8	50.0	348.2	158	161	160	86.9	26.5	102.0
R.C.	1116	2.76	62.9	29.5	253.9	138	134	136	75.6	33.0	72.5
P.C.	911	2.05	50.9	24.9	225.9	118	117	118	65.6	18.0	63.0
V.C.	741	1.68	49.3	26.3	217.5	138	134	136	72.7	16.0	45.4
D.F.	923	2.15	58.6	29.1	251.9	129	136	133	72.3	16.0	60.4
B.G.	1276	3.09	74.2	40.0	306.4	145	150	148	85.5	33.5	88.2
S.G.	720	1.95	51.8	23.3	191.3	138	134	136	75.6	18.0	46.1
L.G.	1076	2.82	73.8	34.5	281.7	141	143	142	82.1	10.0	61.2
D.H.	732	1.65	52.6	24.0	233.9	127	132	130	66.7	23.5	48.8
D.Hr.	732	1.85	55.1	25.8	220.2	132	134	133	76.9	24.5	54.6
C.H.	1281	2.99	69.7	39.8	299.2	173	173	173	94.0	38.0	87.0
B.H.	1271	2.92	68.9	37.4	300.5	164	164	164	84.0	26.0	78.0
J.J.	717	1.73	44.0	21.2	182.8	118	113	116	58.0	19.0	50.0
H.K.	919	2.16	59.7	32.5	254.1	132	132	132	70.6	19.0	68.0
T.K.	729	1.90	58.5	23.4	225.0	129	136	133	73.9	33.0	51.5
J.L.	908	2.39	69.9	35.8	266.0	155	158	157	78.5	27.0	65.5
D.Mc.	723	1.86	58.3	29.5	226.1	130	134	132	67.7	9.5	41.9
T.M.	547	1.40	43.4	19.2	169.2	111	115	113	60.4	20.5	45.6
V.M.	1271	3.27	84.6	46.3	329.0	167	170	169	93.9	25.0	83.9
D.M.	1464	3.30	74.6	48.4	330.8	155	158	157	87.2	33.5	76.5
G.M.	1080	2.58	71.7	37.9	300.8	158	164	161	84.3	8.5	66.6
D.N.	1292	3.27	79.0	44.6	312.2	170	170	170	94.4	40.0	108.6
F.P.	720	2.06	62.8	28.6	220.0	155	164	160	85.6	8.5	58.3
R.P.	911	2.29	63.0	33.8	250.5	148	143	146	76.4	38.0	68.4
A.S.	729	1.77	57.8	29.2	238.6	155	150	153	80.1	28.0	43.7
D.S.	1440	3.36	68.3	33.6	292.4	145	148	147	86.5	23.5	97.9

TABLE XI

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE VENTILATION CURVES

5. RAW DATA FOR THE SECOND WORK-LOAD ABOVE THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min. H.R.	H.R. 4 min. H.R.	H.R. Ave. H.R.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)
A.B.	1800	3.92	83.5	55.1	383.5	170	170	170	92.4	49.0	115.1
R.C.	1318	3.08	70.2	32.9	299.8	155	155	155	86.1	42.0	82.2
P.C.	1116	2.69	66.8	32.7	276.7	129	134	132	73.3	31.5	75.8
V.C.	915	2.10	61.5	32.8	268.6	161	161	161	86.1	30.0	53.5
D.F.	1085	2.41	65.8	32.8	296.2	150	148	149	80 9	25.5	72.6
B.G.	1458	3.49	83.9	45.2	350.1	155	158	157	90.8	52.0	98.7
S.G.	908	2.21	58.7	26.3	241.2	145	145	145	80.6	15.5	59.6
L.G.	1244	3.31	86.6	40.5	325.7	155	158	157	90.8	23.5	65.5
D.H.	911	1.66	53.0	24.2	291.1	148	150	149	76.4	40.5	58.5
D.Hr.	870	2.03	60.4	28.4	261.7	148	148	148	85.5	34.5	69.1
C.H.	1422	3.51	81.9	46.8	332.1	184	187	186	100.0	54.0	105.3
B.H.	1422	3.37	79.6	43.1	336.2	173	176	175	89.7	36.0	84.5
J.J.	923	2.28	58.0	28.0	235.3	132	132	132	66.0	33.0	69.3
H.K.	1094	2.55	70.6	38.5	302.5	153	155	154	82.4	30.0	88.3
T.K.	915	2.32	71.5	28.6	282.4	153	153	153	85.0	38.0	74.2
J.L.	1094	2.77	81.3	41.7	320.5	170	176	173	86.5	48.0	72.5
D.Mc.	900	2.17	67.9	34.4	281.4	150	150	150	76.9	14.0	52.4
T.M.	720	1.82	56.4	25.0	222.7	127	130	129	68.9	25.5	54.0
V.M.											
D.M.	1640	3.68	83.1	53.9	370.6	167	170	169	93.9	41.0	83.0
G.M.	1229				342.2	173	170	172	90.1	24.0	
D.N.	1440	3.51	84.7	47.8	347.9	180	180	180	100.0	60.0	137.2
F.P.	915	2.23	68.1	31.0	279.6	173	176	175	93.6	30.0	68.6
R.P.	1067	2.78	76.4	40.9	293.4	161	164	163	85.3	50.0	81.2
A.S.	896	2.17	70.9	35.8	293.3	167	164	166	86.9	31.5	58.8
D.S.	1647	3.68	74.8	36,8	334.4	155	155	155	91.2	42.0	110.0

TABLE XII

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE LACTATE CURVES

1. RAW DATA FOR THE SECOND WORK-LOAD BELOW THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min.	H.R. 4 min.	H.R. Ave.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)	Wt. (kg)
A.B.	1089	2.35	50.2	33.1	232.0	115	114	115	62.5	12.0	55.4	71.1
R.C.	378	1.18	26.9	12.6	86.0	90	86	88	48.9	10.0	30.8	93.6
P.C.	357	1.09	26.9	13.2	88.5	92	93	93	51.6	8.5	38.4	82.3
V.C.												63.9
D.F.	374	1.14	31.0	15.4	102.1	97	83	90	48.9	10.5	31.0	73.6
B.G.												77.3
S.G.	185	0.93	24.7	11.1	49.1	87	95	91	50.6	10.0	26.2	83.9
L.G.	547	1.64	43.0	20.1	143.2	106	107	107	61.8	6.0	36.5	81.6
D.H.												68.6
D.Hr.												71.6
C.H.	529	1.34	31.0	17.9	123.5	129	122	126	68.5	14.5	37.6	75.0
B.H.	720	1.84	43.6	23.6	170.3	132	130	131	67.2	7.5	42.8	78.1
J.J.	189	0.93	23.6	11.4	48.1	87	92	90	45.0	8.5	30.0	81.4
H.K.	365	1.00	27.8	15.1	100.9	101	99	100	53.5	11.5	25.0	66.4
T.K.	183	0.77	23.9	9.6	56.5	79	89	84	46.7	21.0	25.7	80.9
J.L.	182	0.85	25.0	12.8	53.3	96	91	94	47.0	18.0	28.8	66.6
D.Mc.	182	0.70	21.9	11.1	56.9	92	95	94	48.2	5.5	18.2	63.2
T.M.	183	0.84	26.0	11.5	56.6	90	92	91	48.7	8.5	27.5	72.9
V.M.	547	1.59	41.3	22.6	141.6	113	117	115	63.9	8.0	41.8	70.6
D.M.	915	2.24	50.6	32.8	206.8	125	132	129	71.7	11.0	57.4	68.2
G.M.	723	1.84	51.1	27.1	201.3	132	132	132	69.1	6.5	40.2	67.8
D.N.												73.3
F.P.	363	1.21	36.9	16.8	110.9	125	132	129	68.9	6.0	32.8	71.8
R.P.												67.8
A.S.												60.5
D.S.	919	2.22	45.1	22.2	186.6	107	110	109	64.1	14.0	56.4	100.0

TABLE XII

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE LACTATE CURVES

2. RAW DATA FOR THE FIRST WORK-LOAD BELOW THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (1/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min.	H.R. 4 min.	H.R. Ave.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (1/min.)
A.B.	1297	2.85	60.6	40.0	276.4	136	136	136	73.9	9.5	67.4
R.C.	551	1.50	34.2	16.1	125.3	100	100	100	55.5	11.0	39.0
P.C.	524	1.38	34.2	16.8	129.9	101	95	98	54.0	10.0	37.7
V.C.	374	0.97	28.3	15.1	109.8	97	97	97	51.9	12.0	30.7
D.F.	572	1.61	44.0	21.9	156.2	98	105	102	55.4	9.5	40.1
B.G.	549	1.40	33.7	18.2	131.8	98	98	98	56.6	11.0	36.4
S.G.	365	1.21	32.2	14.4	96.9	102	102	102	56.7	10.5	31.2
L.G.	726	2.00	52.5	24.6	190.1	118	118	118	68.2	6.5	42.0
D.H.	185	0.72	22.9	10.5	59.1	92	90	91	46.7	7.5	23.0
D.Hr.	375	1.17	34.9	16.4	112.8	87	91	89	51.4	12.5	37.9
C.H.	726	1.87	43.8	24.9	169.5	141	136	139	75.5	17.0	49.2
B.H.	904	2.28	53.9	29.2	213.8	138	138	138	70.8	13.0	53.7
J.J.	362	1.03	26.2	12.6	92.3	94	98	96	48.0	13.5	30.0
H.K.	551	1.38	38.2	20.8	152.4	100	100	100	53.5	8.0	32.2
T.K.	366	1.04	32.1	12.9	113.0	100	105	103	57.2	23.5	31.5
J.L.	360	1.17	34.3	17.6	105.5	105	107	106	53.0	18.5	32.5
D.Mc.	365	1.06	33.1	16.8	114.1	107	113	110	56.4	5.5	23.6
T.M.	360	1.17	36.1	16.0	111.4	103	98	101	54.0	21.0	32.9
V.M.	729	1.97	50.9	27.9	188.7	129	129	129	71.7	10.5	51.7
D.M.	1094	2.54	57.4	37.2	247.2	138	138	138	76.7	9.5	62.9
G.M.	904	2.07	57.5	30.5	251.7	150	150	150	78.5	8.0	49.2
D.N.	522	1.22	29.4	16.6	126.1	111	106	109	60.6	6.5	39.4
F.P.	545	1.43	43.6	19.9	166.6	145	141	143	76.5	13.5	41.7
R.P.	369	1.08	29.6	15.9	101.5	105	105	105	54.9	14.0	31.0
A.S.	176	0.88	28.6	14.5	57.6	118	118	118	61.8	13.0	25.4
D.S.	1094	2.69	54.6	26.9	222.7	118	114	116	68.2	13.0	64.5

TABLE XII

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE LACTATE CURVES

3. RAW DATA FOR THE WORK-LOAD AT THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min. H.R.	H.R. 4 min. H.R.	H.R. Ave. H.R.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)
A.B.	1470	3.14	66.9	44.1	313.2	145	148	147	79.9	8.5	81.5
R.C.	732	1.94	44.1	20.7	166.5	110	106	108	60.0	13.5	47.3
P.C.	726	1.85	45.8	22.5	180.0	110	111	111	61.7	13.0	44.9
V.C.	556	1.28	37.6	20.1	163.2	115	115	115	61.5	11.5	36.5
D.F.	741	1.82	49.6	24.7	202.3	111	113	112	60.9	11.5	48.3
B.G.	732	1.81	43.4	23.4	175.8	107	108	108	62.4	11.5	45.1
S.G.	540	1.44	38.2	17.1	143.5	113	108	111	61.7	11.5	36.7
L.G.	911	2.39	62.5	29.2	238.5	129	127	128	73.9	7.0	50.8
D.H.	366	0.98	31.4	14.3	116.9	102	103	103	52.8	8.0	29.6
D.Hr.	560	1.48	43.9	20.6	168.4	113	111	112	64.7	15.0	42.1
C.H.	926	2.36	55.0	31.4	216.3	150	150	150	81.5	21.0	62.9
B.H.	1040	2.30	54.3	29.4	245.9	148	150	149	76.4	13.5	60.5
J.J.	531	1.36	34.5	16.7	135.4	105	105	105	52.5	14.5	35.6
H.K.	729	1.74	48.1	26.2	201.6	115	113	114	60.9	12.5	43.2
T.K.	551	1.31	40.4	16.2	170.1	111	110	111	61.7	25.5	35.2
J.L.	549	1.45	42.4	21.7	160.9	120	120	120	60.0	17.5	40.7
D.Mc.	545	1.42	44.2	22.4	170.4	123	122	123	63.1	6.0	31.9
T.M.	547	1.40	43.4	19.2	169.2	111	115	113	60.4	20.5	45.6
V.M.	904	2.32	60.1	32.9	234.0	141	138	140	77.8	8.5	60.9
D.M.	1276	2.82	63.7	41.3	288.4	143	148	146	81.1	13.0	67.9
G.M.	1080	2.58	71.7	37.9	300.8	158	164	161	84.3	8.5	66.6
D.N.	705	1.83	44.3	25.0	170.4	123	125	124	68.9	8.0	53.7
F.P.	720	2.06	62.8	28.6	220.0	155	164	160	85.6	8.5	58.3
R.P.	549	1.55	42.7	22.9	150.9	111	114	113	59.2	16.0	47.6
A.S.	363	1.10	35.9	18.1	118.8	129	122	126	65.9	17.0	27.8
D.S.	1255	3.07	62.4	30.7	254.8	132	134	133	78.2	14.5	73.1

TABLE XII

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE LACTATE CURVES

4. RAW DATA FOR THE FIRST WORK-LOAD ABOVE THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min.	H.R. 4 min.	H.R. Ave.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)
A.B.	1634	3.56	75.8	50.0	348.2	158	161	160	86.9	26.5	102.0
R.C.	923	2.11	48.0	22.5	210.0	129	122	126	70.0	17.5	54.1
P.C.	911	2.05	50.9	24.9	225.9	118	117	118	65.6	18.0	63.0
V.C.	741	1.68	49.3	26.3	217.5	138	134	136	72.7	16.0	45.4
D.F.	923	2.15	58.6	29.1	251.9	129	136	133	72.3	16.0	60.4
B.G.	908	2.20	52.7	28.4	218.1	118	122	120	69.4	24.0	57.7
S.G.	720	1.95	51.8	23.3	191.3	138	134	136	75.6	18.0	46.1
L.G.	1076	2.82	73.8	34.5	281.7	141	143	142	82.1	10.0	61.2
D.H.	547	1.28	40.9	18.6	174.8	113	113	113	57.9	13.5	36.5
D.Hr.	732	1.85	55.1	25.8	220.2	132	134	133	76.9	24.5	54.6
C.H.	1094	2.45	58.4	33.3	255.5	161	164	163	88.6	30.0	68.1
B.H.	1271	2.92	68.9	37.4	300.5	164	164	164	84.0	26.0	78.0
J.J.	717	1.73	44.0	21.2	182.8	118	113	116	58.0	19.0	50.0
H.K.	919	2.16	59.7	32.5	254.1	132	132	132	70.6	19.0	68.0
T.K.	729	1.90	58.5	23.4	225.0	129	136	133	73.9	33.0	51.5
J.L.	729	1.90	55.8	28.6	213.6	138	134	136	68.0	23.0	48.9
D.Mc.	723	1.86	58.3	29.5	226.1	130	134	132	67.7	9.5	41.9
T.M.	720	1.82	56.4	25.0	222.7	127	130	129	68.9	25.5	54.0
V.M.	1080	2.73	70.5	38.6	279.6	155	153	154	85.6	19.5	69.0
D.M.	1464	3.30	74.6	48.4	330.8	155	158	157	87.2	33.5	76.5
G.M.	1229				342.2	173	170	172	90.1	24.0	
D.N.	908	2.27	54.8	30.9	219.4	136	141	139	77.2	38.0	68.6
F.P.	915	2.23	68.1	31.0	279.6	173	176	175	93.6	30.0	68.6
R.P.	735	1.99	54.6	29.3	202.1	129	129	129	67.5	27.5	56.0
A.S.	542	1.34	43.8	22.2	177.4	136	129	133	69.6	25.0	30.0
D.S.	1440	3.36	68.3	33.6	292.4	145	148	147	86.5	23.5	97.9

TABLE XII

RAW DATA ASSOCIATED WITH THE DETERMINATION OF THE MAC FROM THE LACTATE CURVES

5. RAW DATA FOR THE SECOND WORK-LOAD ABOVE THE MAXIMAL AEROBIC CAPACITY

S.	W.L. (kpm/min.)	$\dot{V}O_2$ (l/min.)	$\dot{V}O_2$ (% of $\dot{V}O_2$max.)	$\dot{V}O_2$ (ml/kg/min.)	W.L. / $\dot{V}O_2$max.	H.R. 2 min.	H.R. 4 min.	H.R. Ave.	H.R. (% of H.R.max.)	Lactate (mg%)	$\dot{V}e$. (l/min.)
A.B.	1800	3.92	83.5	55.1	383.5	170	170	170	92.4	49.0	115.1
R.C.	1116	2.76	62.9	29.5	253.9	138	134	136	75.6	33.0	72.5
P.C.	1116	2.69	66.8	32.7	276.7	129	134	132	73.3	31.5	75.8
V.C.	915	2.09	61.5	32.8	268.6	161	161	161	86.1	30.0	53.5
D.F.	1085	2.41	65.8	32.8	296.2	150	148	149	80.9	25.5	72.6
B.G.	1098	2.58	62.0	33.4	263.7	136	136	136	78.6	28.0	68.0
S.G.	908	2.21	58.7	26.3	241.2	145	145	145	80.6	15.5	59.6
L.G.	1244	3.31	86.6	40.5	325.7	155	158	157	90.8	23.5	65.5
D.H.	732	1.65	52.6	24.0	233.9	127	132	130	66.7	23.5	48.8
D.Hr.	870	2.03	60.4	28.4	261.7	148	148	148	85.5	34.5	69.1
C.H.	1281	2.99	69.7	39.8	299.2	173	173	173	94.0	38.0	87.0
B.H.	1422	3.37	79.6	43.1	336.2	173	176	175	89.7	36.0	84.5
J.J.	923	2.28	58.0	28.0	235.3	132	132	132	66.0	33.0	69.3
H.K.	1094	2.55	70.6	38.5	302.5	153	155	154	82.4	30.0	88.3
T.K.	915	2.32	71.5	28.6	282.4	153	153	153	85.0	38.0	74.2
J.L.	908	2.39	69.9	35.8	266.0	155	158	157	78.5	27.0	65.5
D.Mc.	900	2.17	67.9	34.4	281.4	150	150	150	76.9	14.0	52.5
T.M.	908	2.22	68.7	30.4	280.9	148	145	147	78.6	33.5	70.7
V.M.	1271	3.27	84.6	46.3	329.0	167	170	169	93.9	25.0	83.9
D.M.	1640	3.68	83.1	53.9	370.6	167	170	169	93.9	41.0	83.0
G.M.											
D.N.	1094	2.86	69.0	38.9	264.4	155	164	160	88.9	31.5	83.4
F.P.											
R.P.	911	2.29	63.0	33.8	250.5	148	143	146	76.4	38.0	68.4
A.S.	729	1.77	57.8	29.2	238.6	155	150	153	80.1	28.0	43.7
D.S.	1647	3.68	74.8	36.8	334.4	155	155	155	91.2	42.0	110.0

APPENDIX E

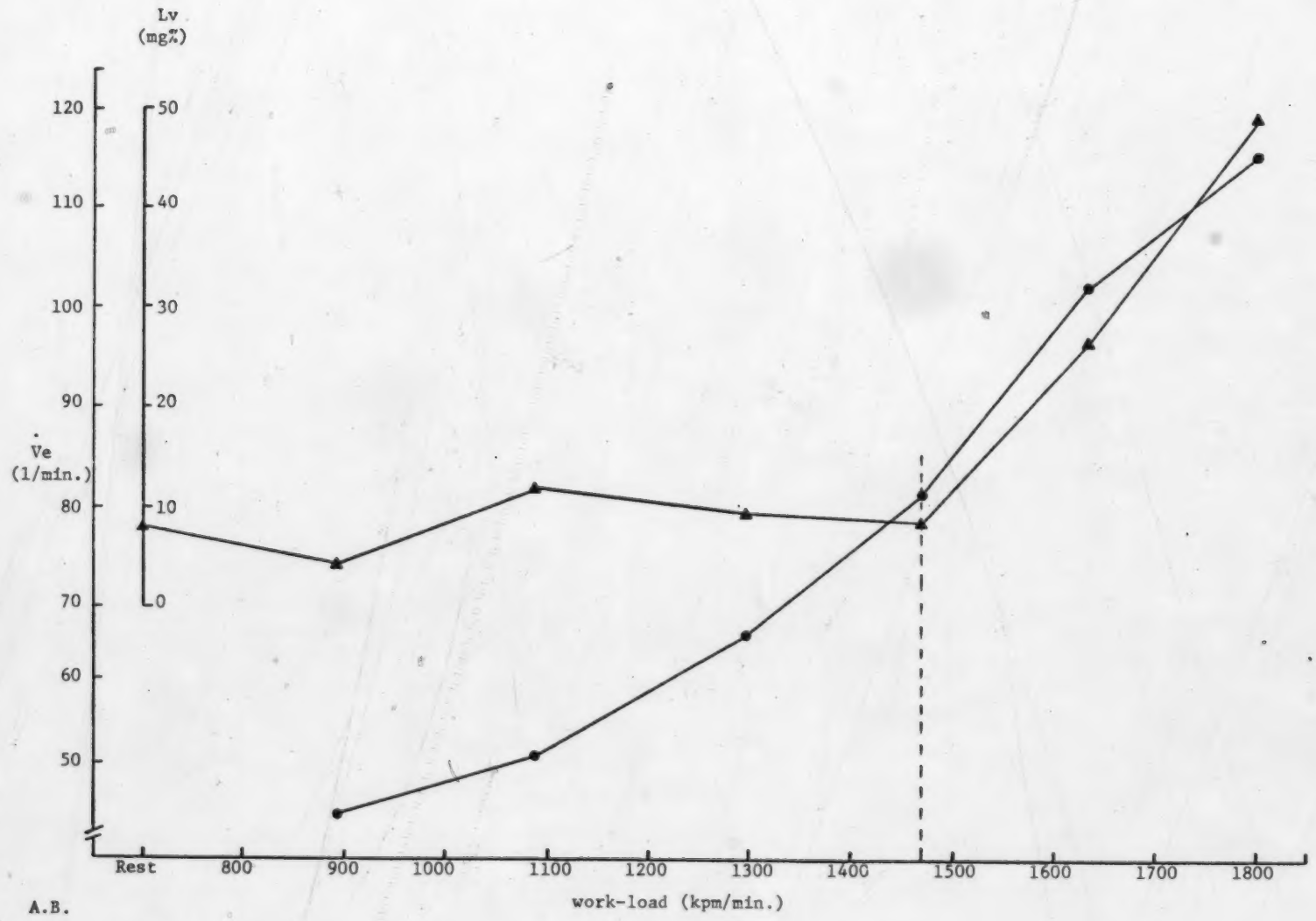
VALUES OF VENTILATION (l/min.) AND BLOOD LACTATE (mg%) PLOTTED AGAINST WORK-LOAD TO DETERMINE THE MAXIMAL AEROBIC CAPACITY - FOR EACH SUBJECT

The maximal aerobic capacity of each subject was determined separately from the ventilation curve (Ve) and from the blood lactate curve (Lv) plotted against work-load. The MAC is indicated by the vertical line. In cases where the MAC's do not correspond as indicated by the two curves, the vertical lines are labelled to indicate from which curve the MAC was chosen.

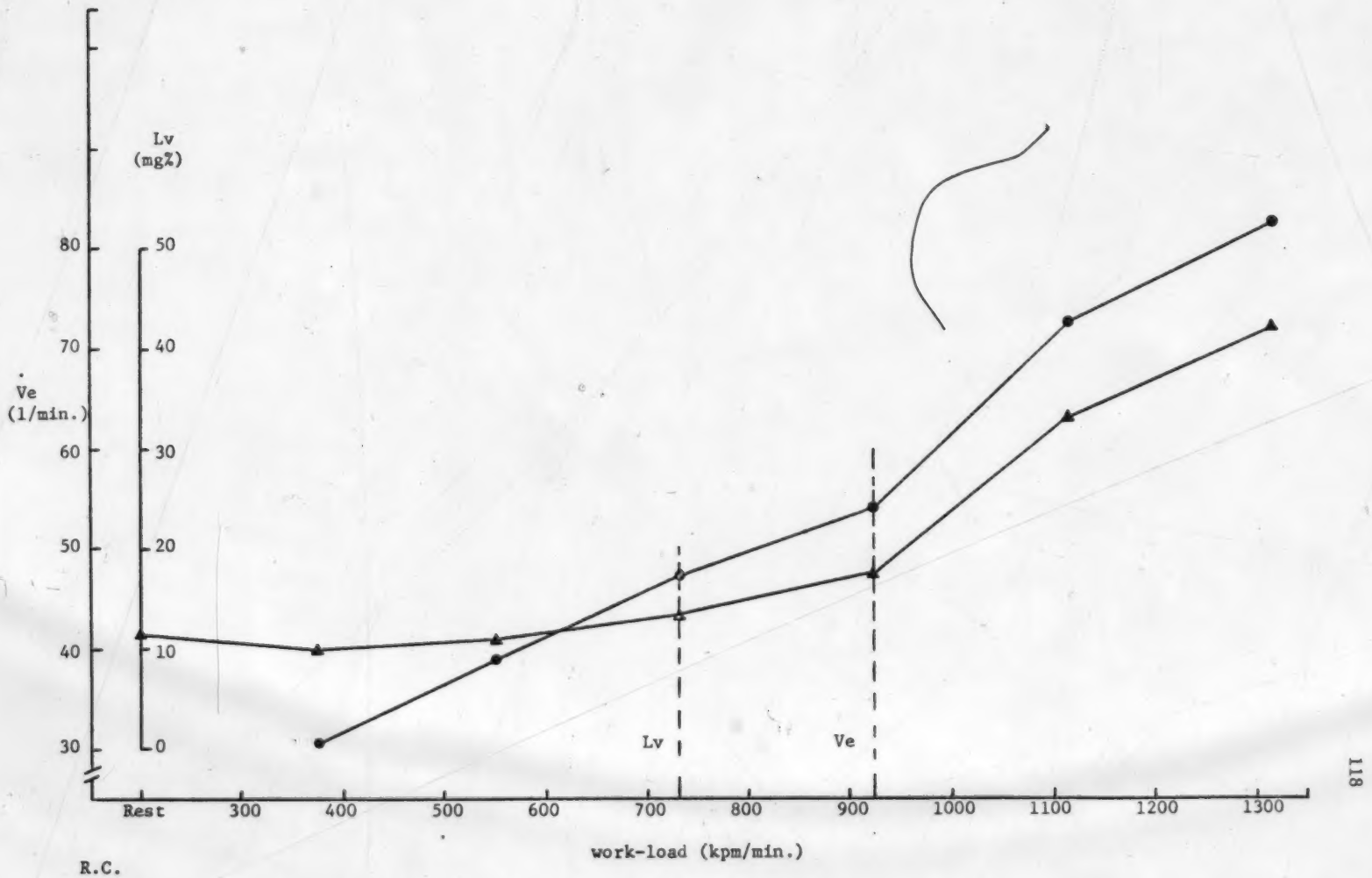
Legend:

Blood lactate = Lv = ▲

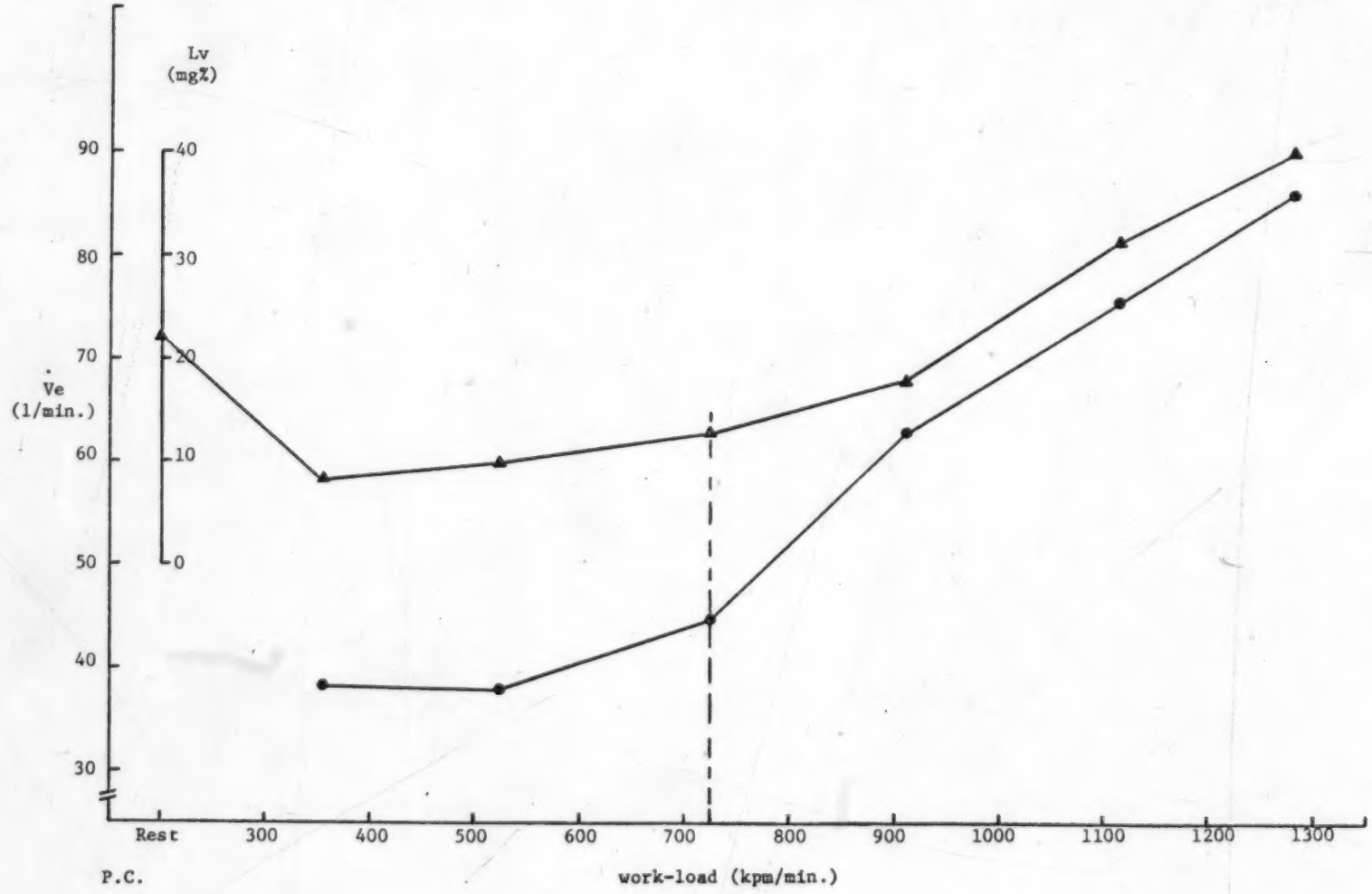
Ventilation = Ve = ●

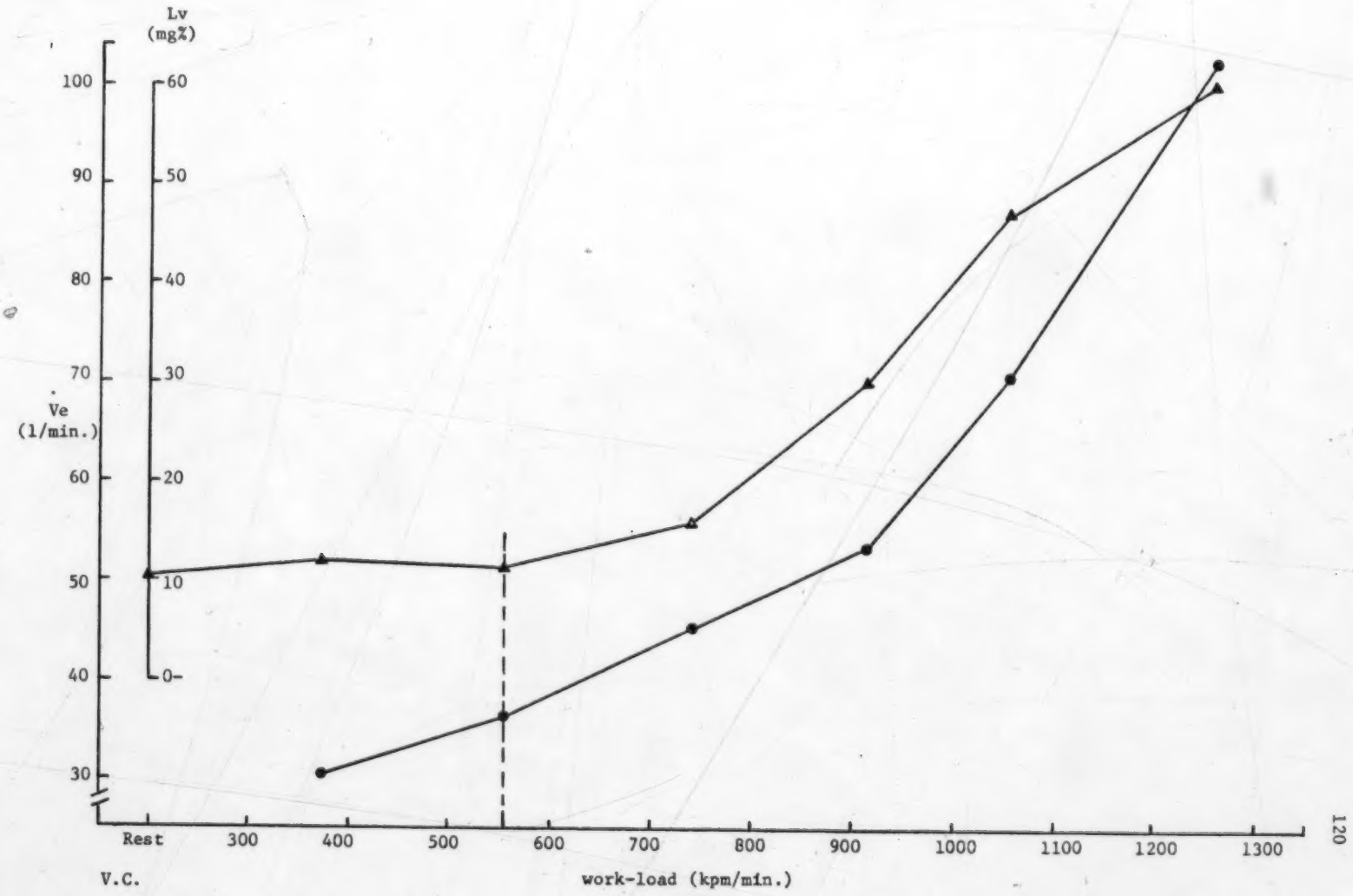

Lv
(mg%)
120
110
100
90
Ve
(l/min.)
80
70
60
50
50
40
30
20
10
0
Rest
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
work-load (kpm/min.)

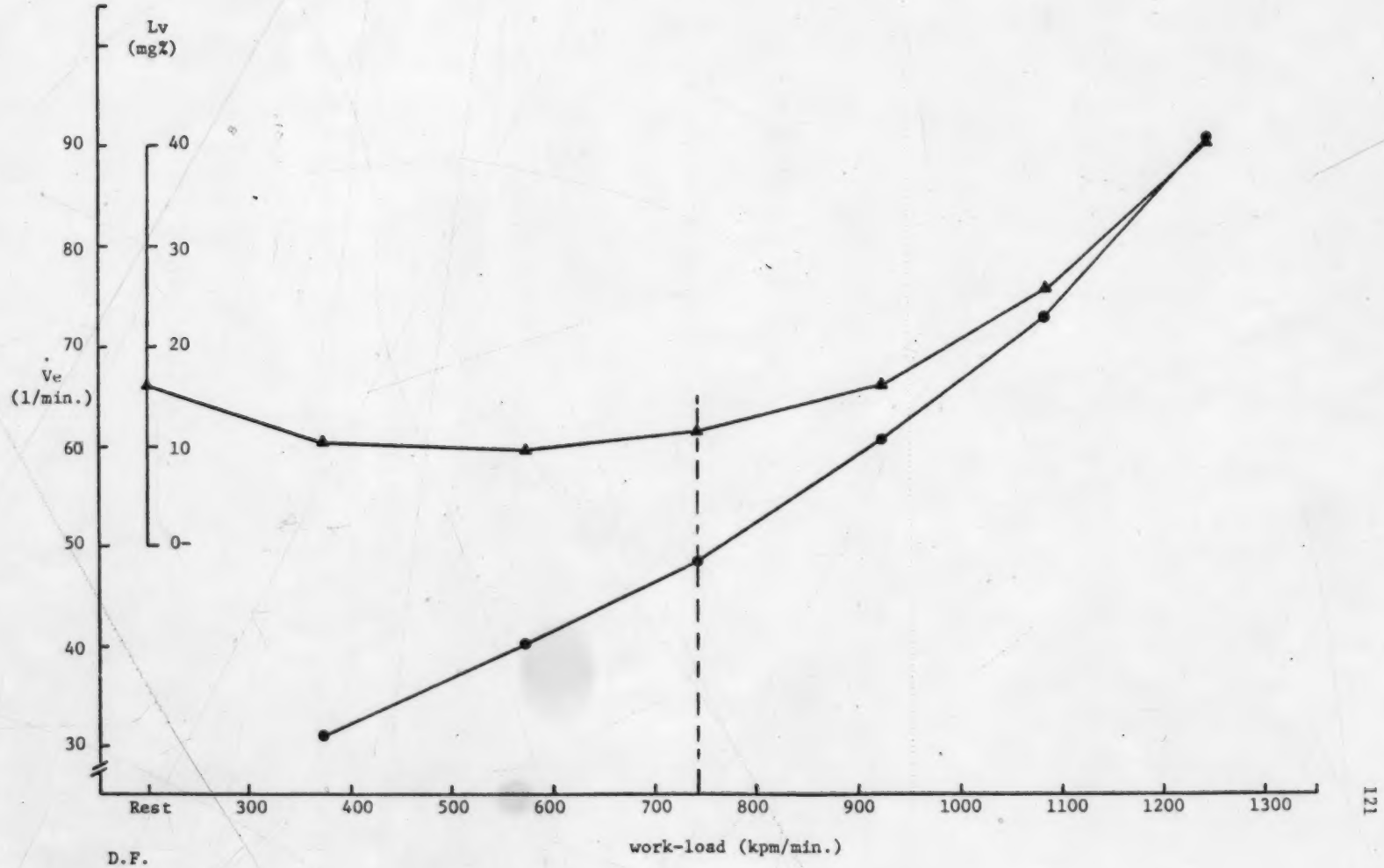
A.B.


Lv
(mg%)
80
70
Ve
(1/min.)
60
50
40
30
50
40
30
20
10
0
Lv
Ve
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
work-load (kpm/min.)

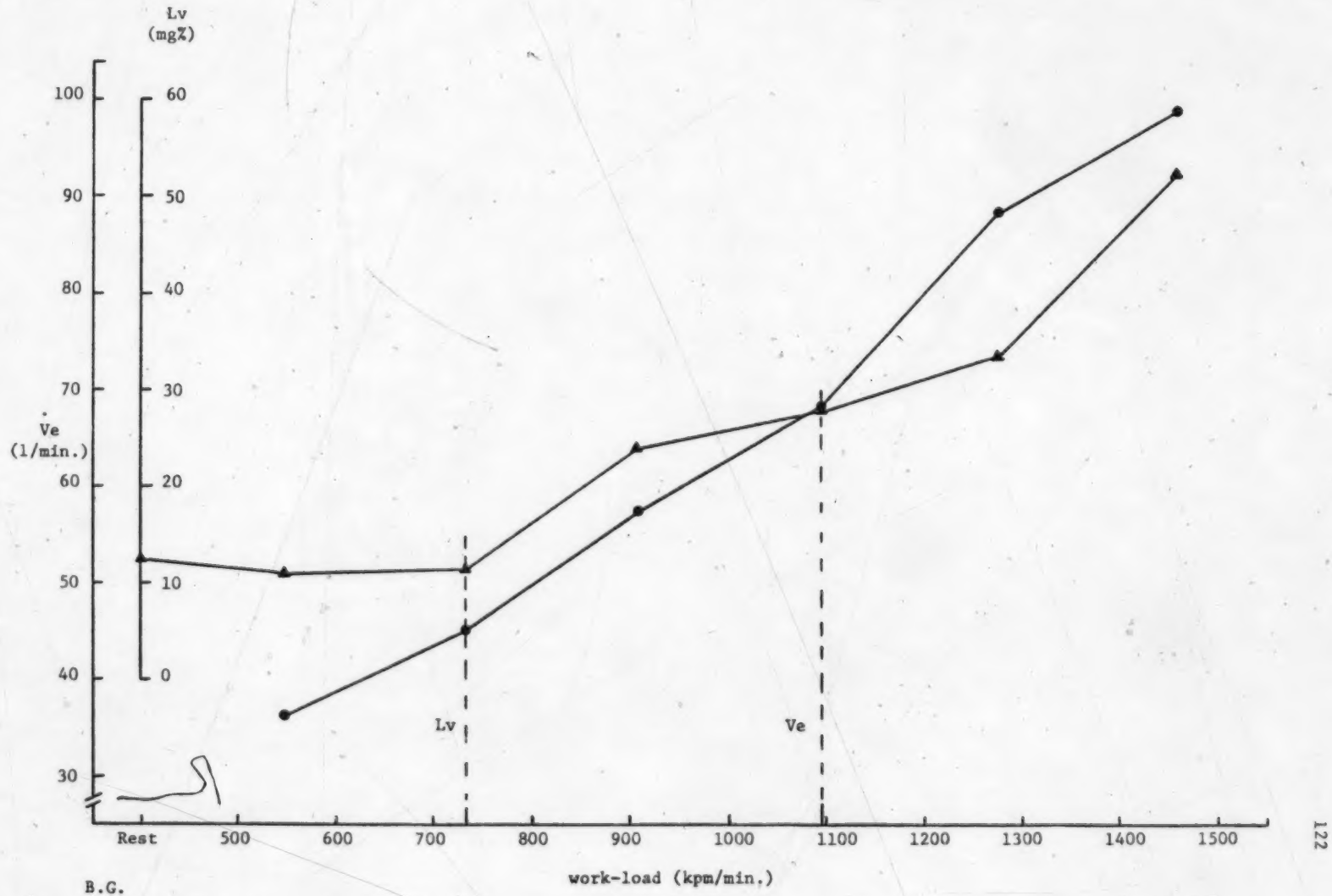
R.C.


Lv
(mg%)
40
30
20
10
0
90
80
70
60
50
40
30
V̇e
(l/min.)
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
P.C.
work-load (kpm/min.)

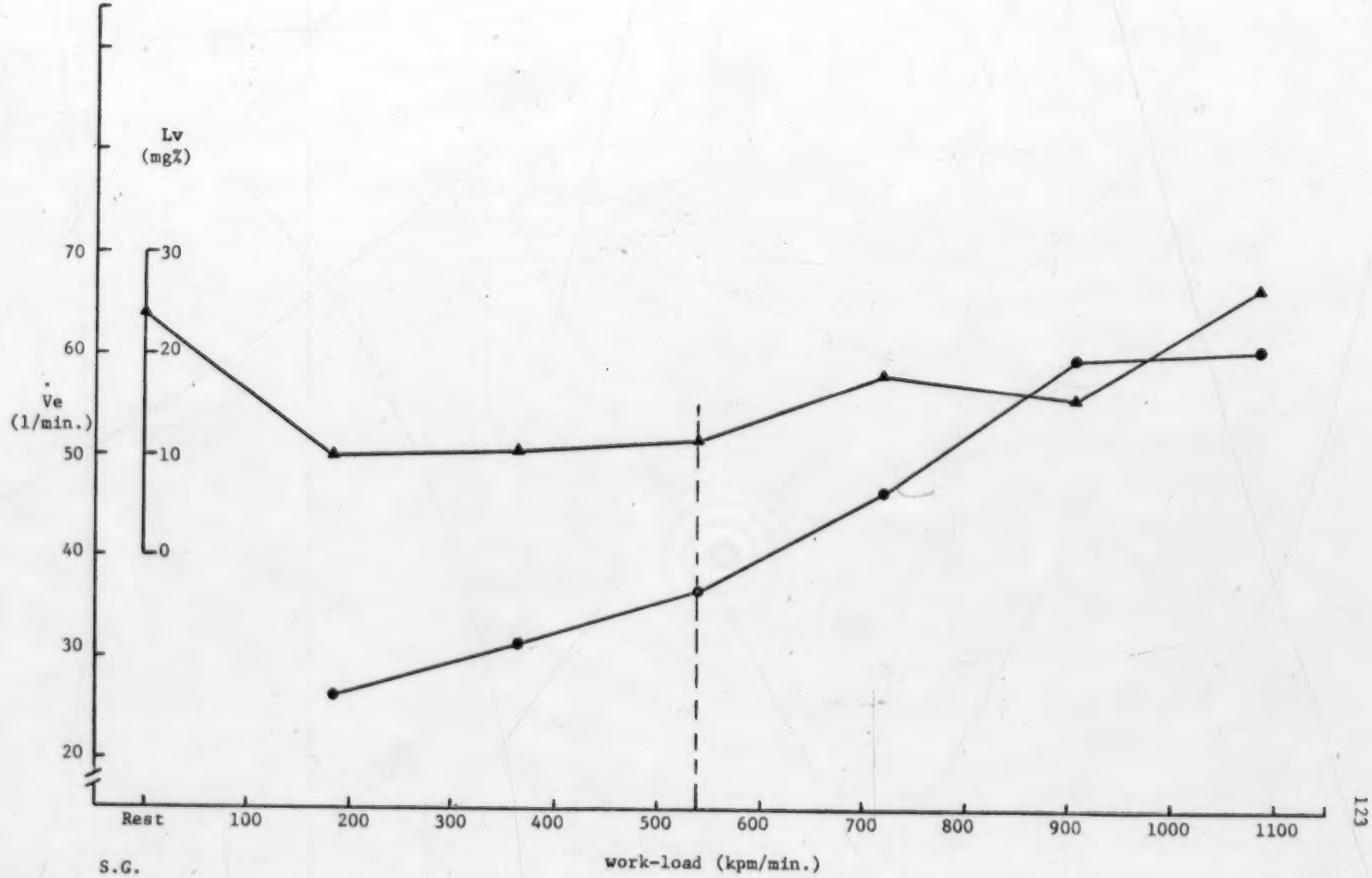

Lv
(mg%)
100
90
80
70
Ve
(l/min.)
60
50
40
30
60
50
40
30
20
10
0
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
V.C.
work-load (kpm/min.)


Lv
(mg%)
40
30
20
10
0
90
80
70
Ve
(l/min.)
60
50
40
30
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
work-load (kpm/min.)

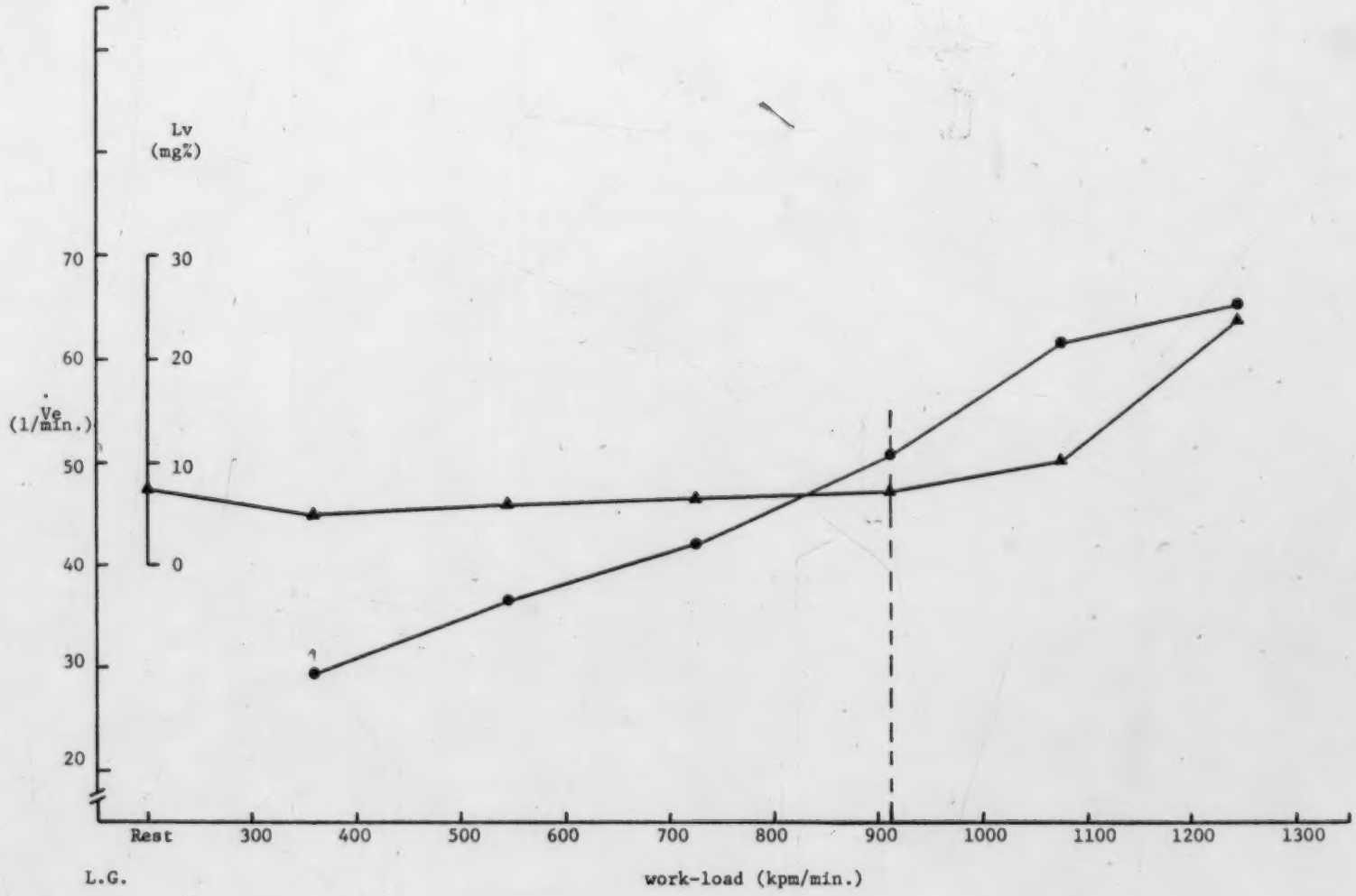
D.F.

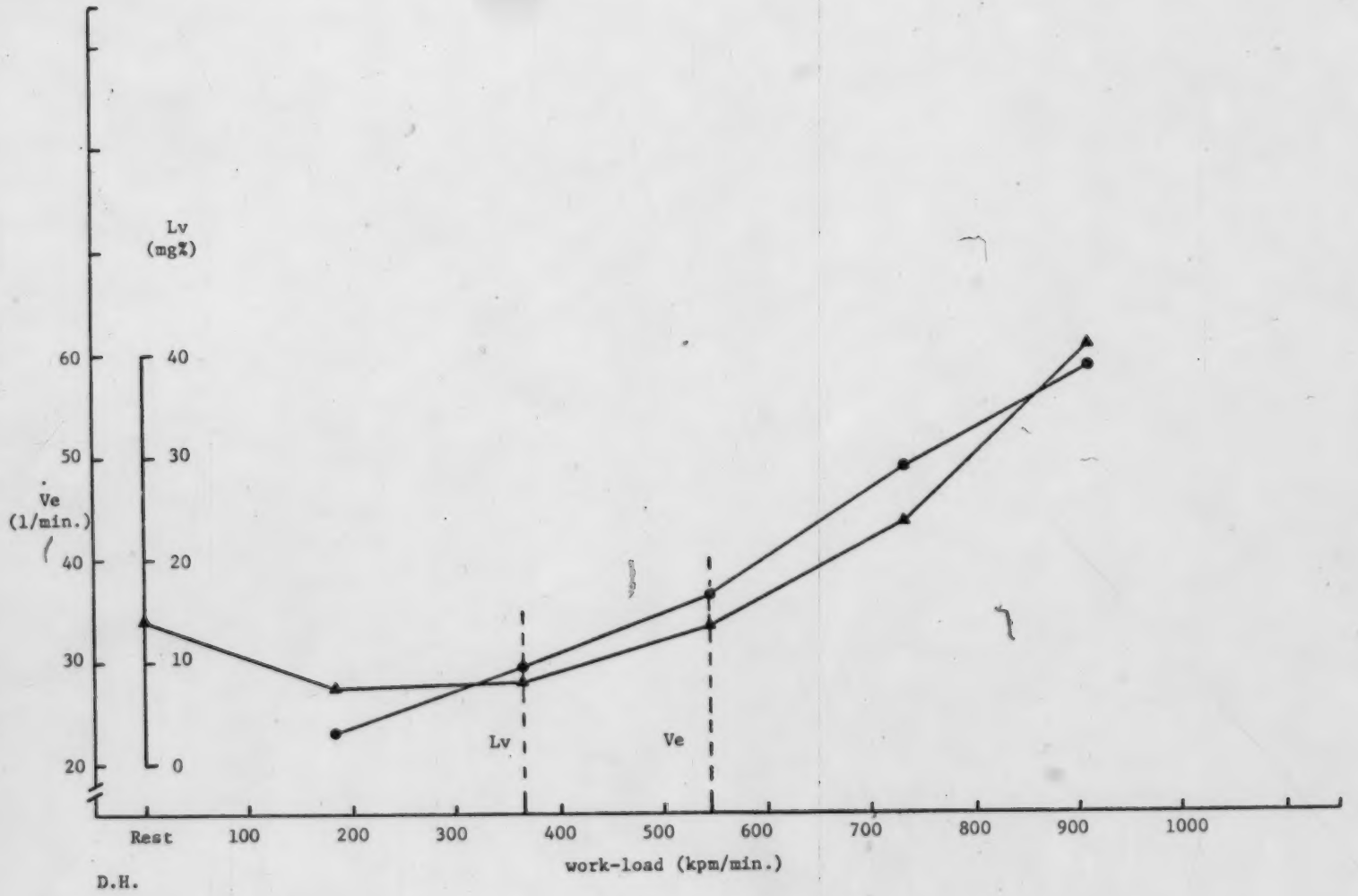

Lv
(mg%)
100
90
80
70
Ve
(l/min.)
60
50
40
30
60
50
40
30
20
10
0
Lv
Ve
Rest
500
600
700
800
900
1000
1100
1200
1300
1400
1500
work-load (kpm/min.)

B.G.

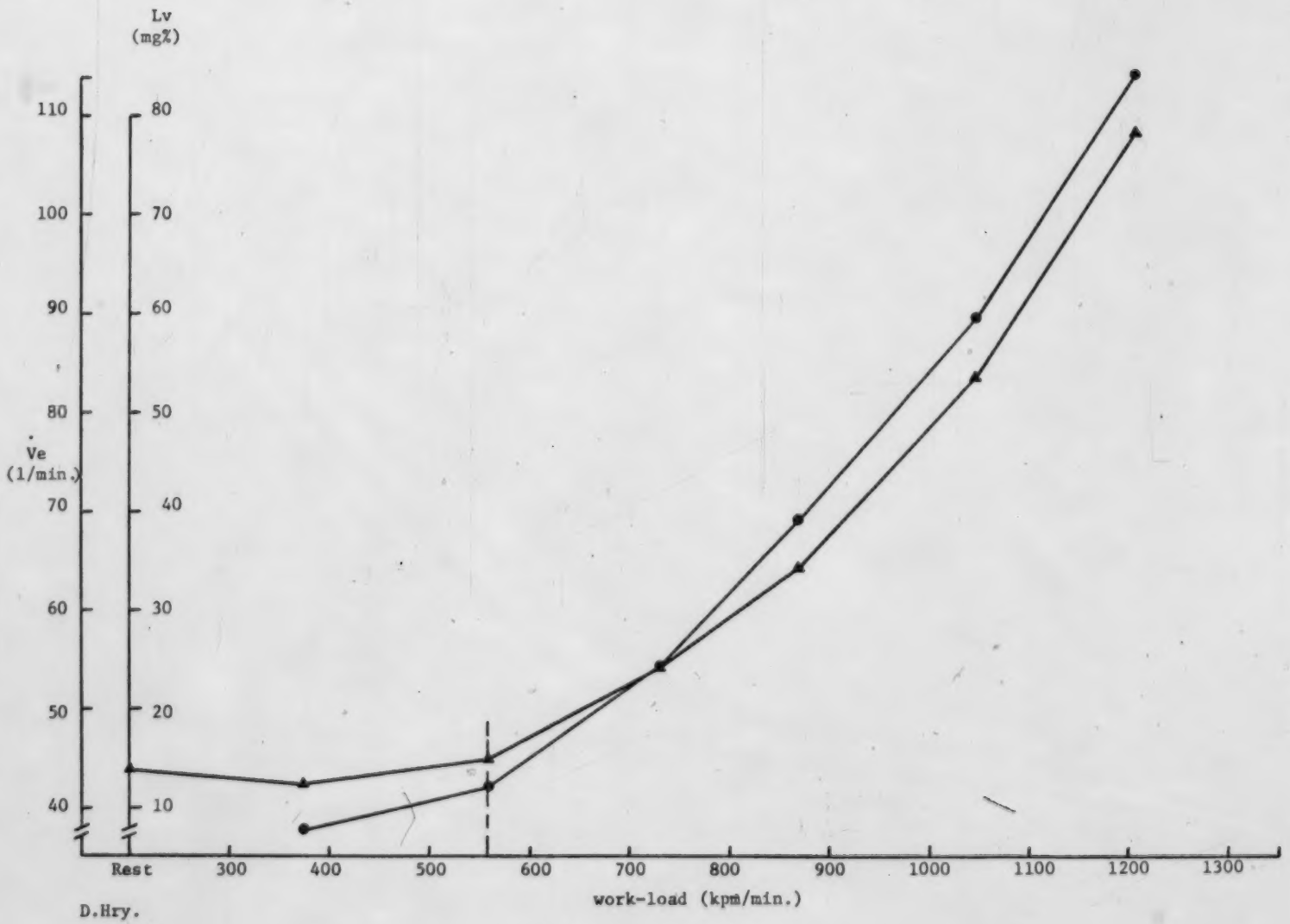

Lv
(mg%)
30
20
10
0
70
60
50
40
30
20
Ve
(1/min.)
Rest
100
200
300
400
500
600
700
800
900
1000
1100
work-load (kpm/min.)

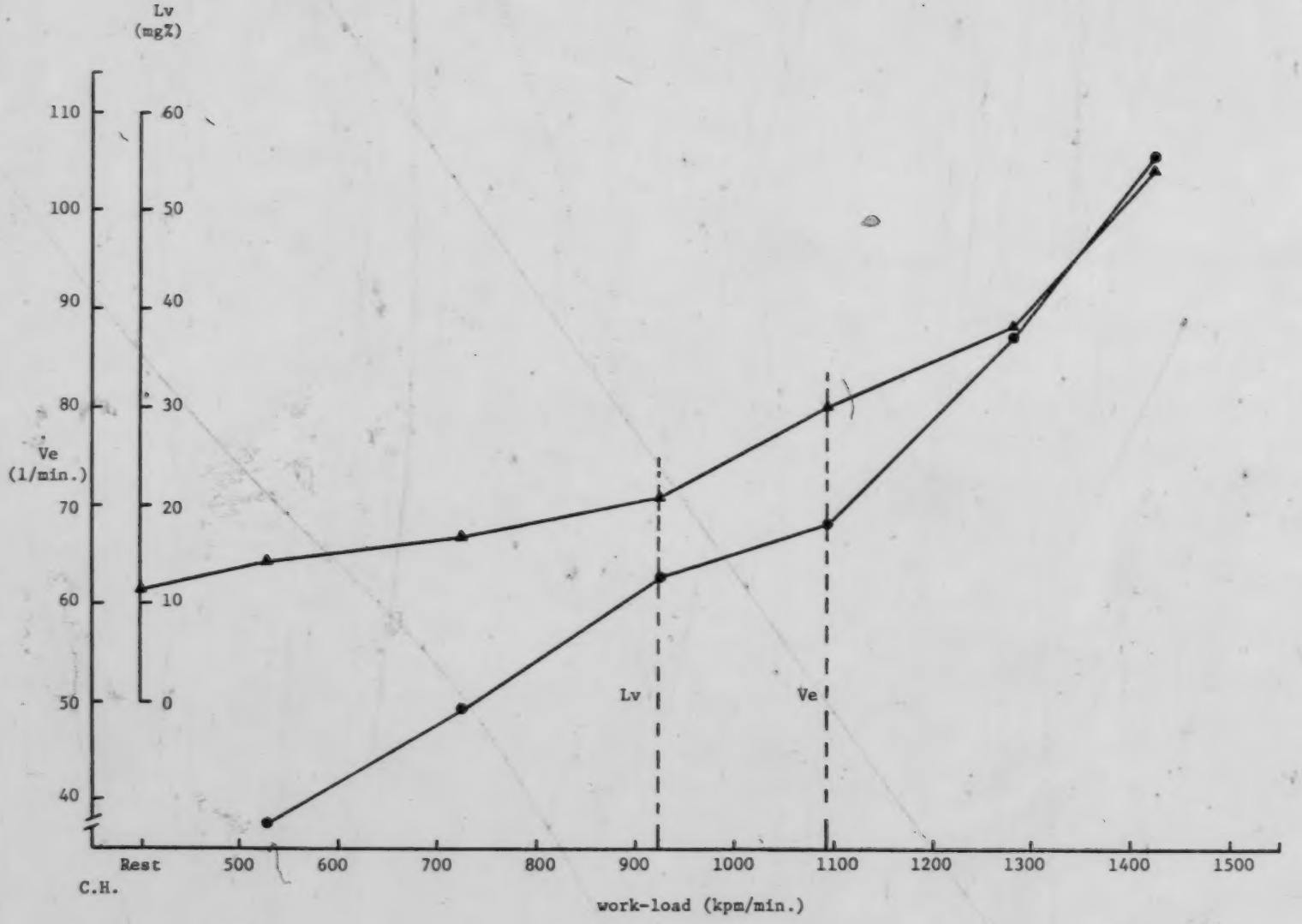
S.G.

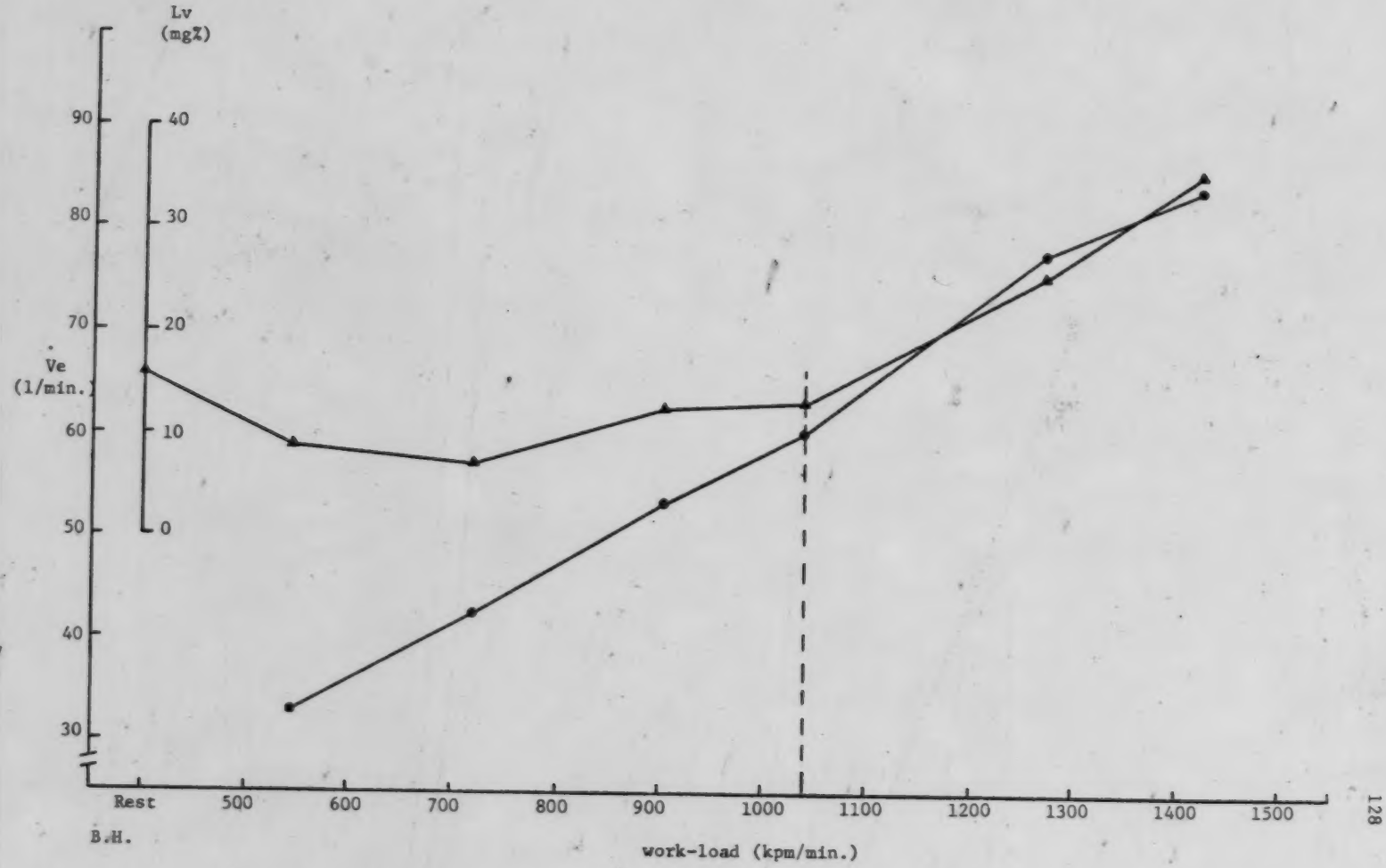

Lv
(mg%)
30
20
10
0
70
60
50
40
30
20
Ve
(l/min.)
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
L.G.
work-load (kpm/min.)

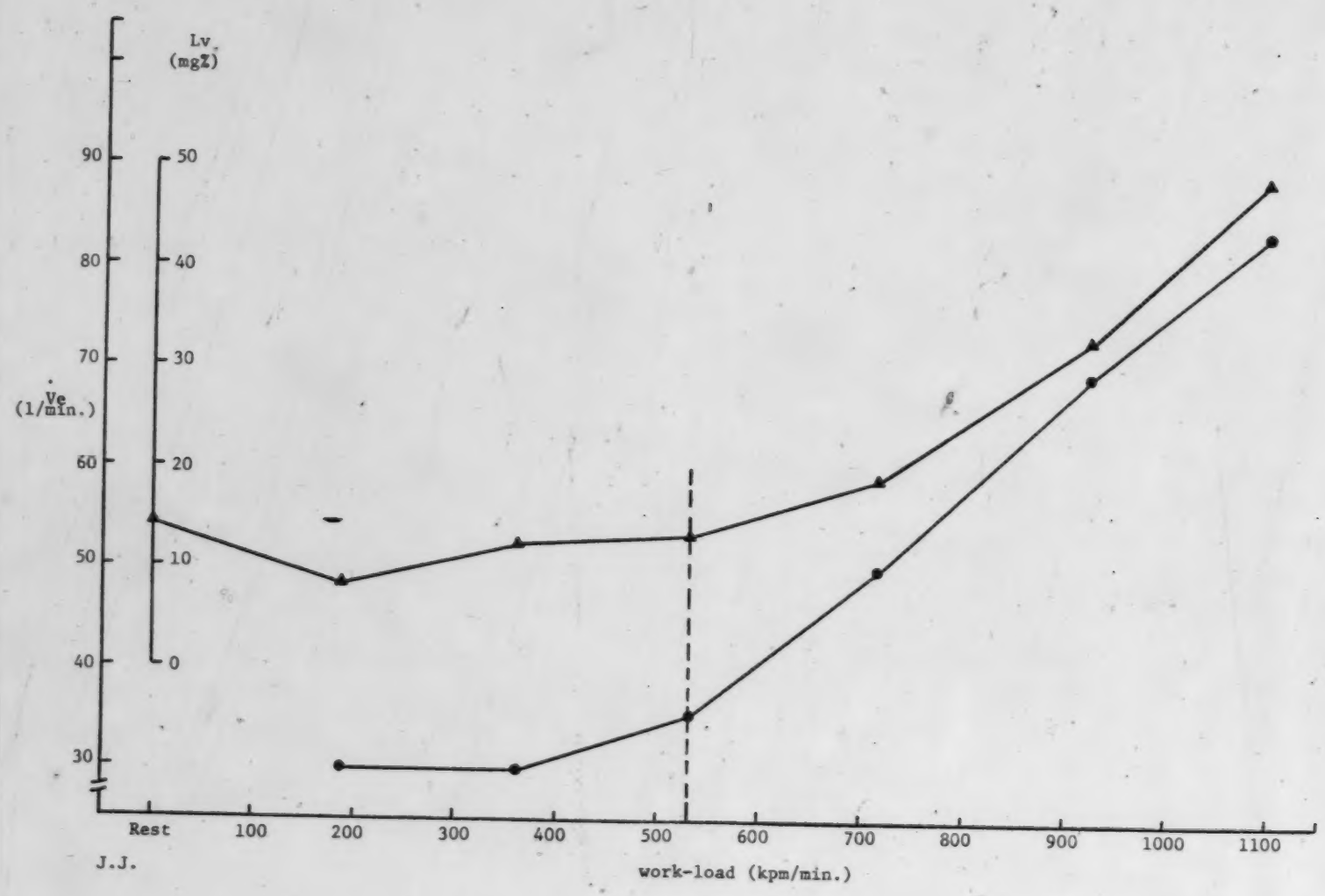

Lv
(mg%)
60
50
40
30
20
40
30
20
10
0
Ve
(1/min.)
Lv
Ve
Rest
100
200
300
400
500
600
700
800
900
1000
work-load (kpm/min.)

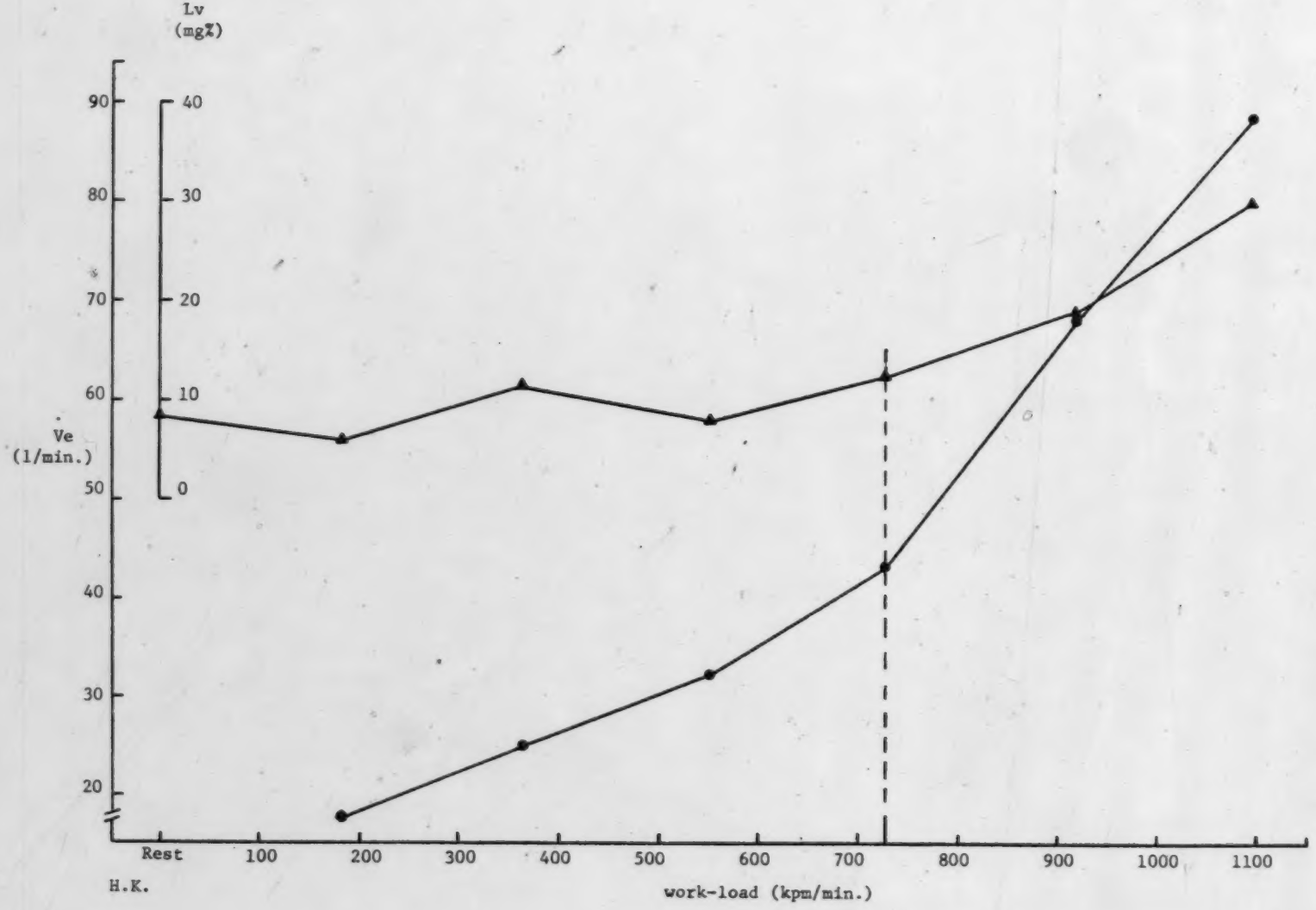
D.H.


Lv
(mg%)
110
100
90
80
70
60
50
40
80
70
60
50
40
30
20
10
Ve
(1/min.)
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
work-load (kpm/min.)
D.Hry.

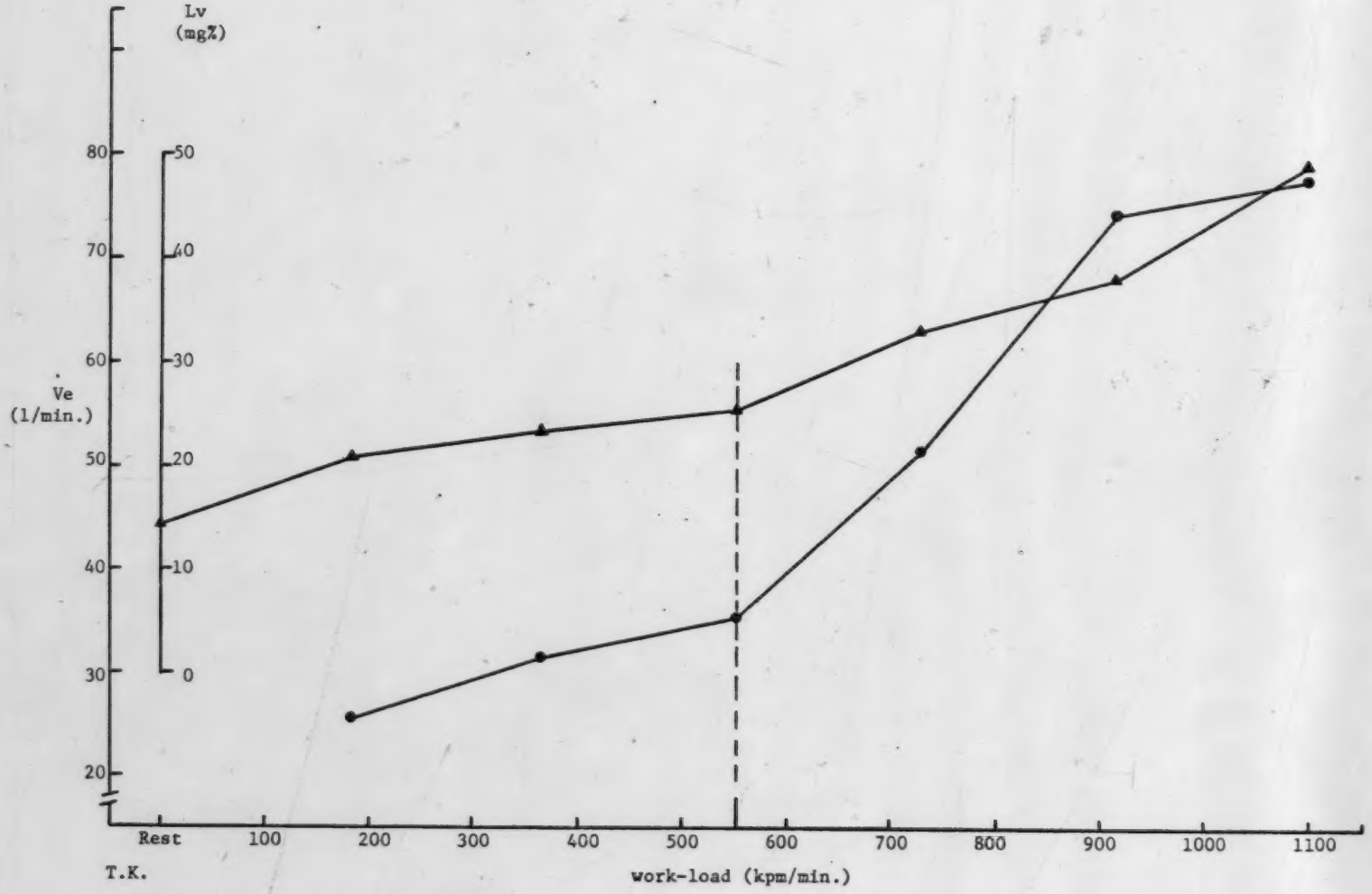

Lv
(mgZ)
110
100
90
80
70
60
50
40
60
50
40
30
20
10
0
Ve
(l/min.)
Lv
Ve
Rest
C.H.
500
600
700
800
900
1000
1100
1200
1300
1400
1500
work-load (kpm/min.)

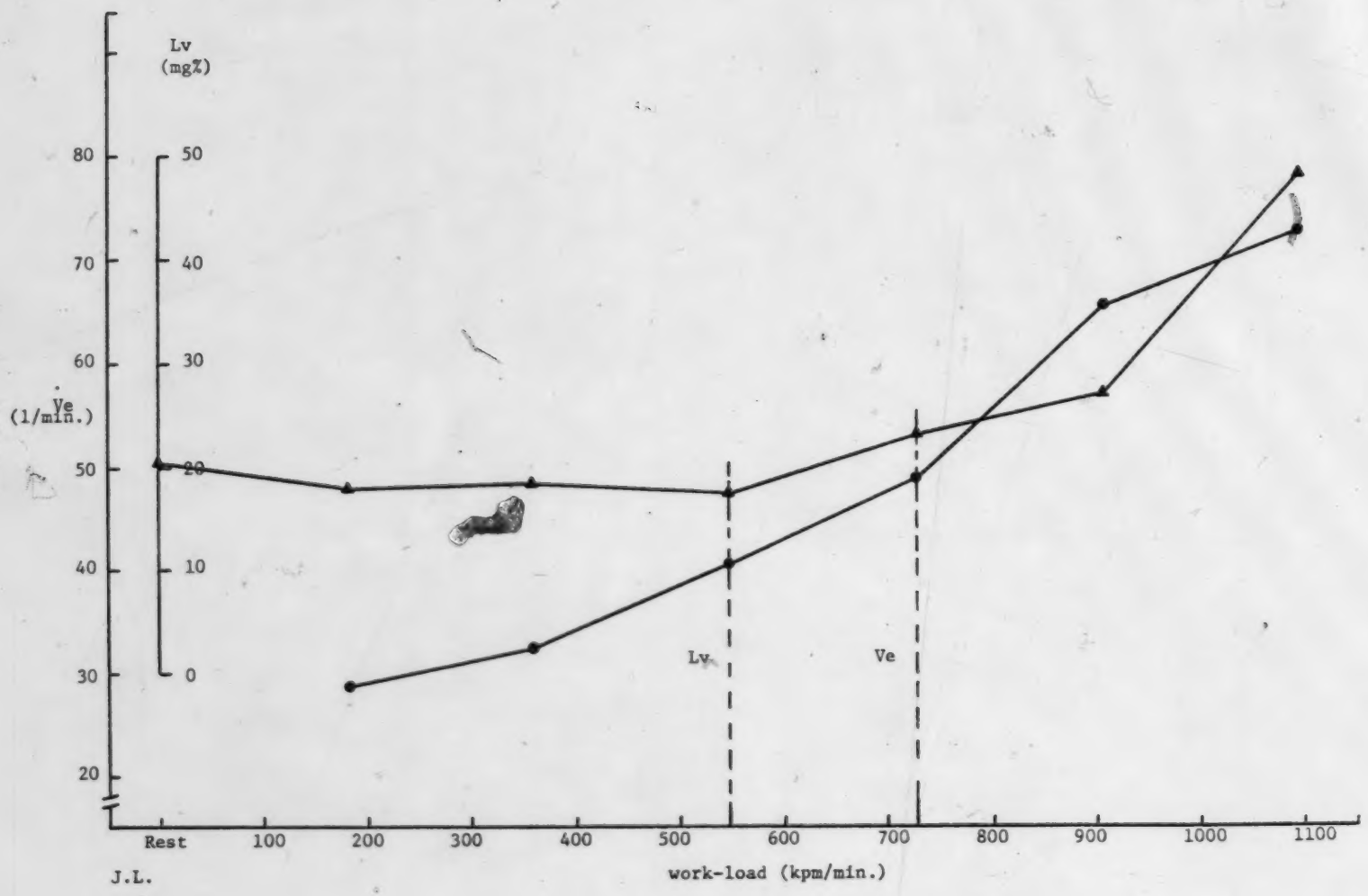

Lv
(mg%)
40
30
20
10
0
90
80
70
Ve
(l/min.)
60
50
40
30
Rest
B.H.
500
600
700
800
900
1000
1100
1200
1300
1400
1500
work-load (kpm/min.)

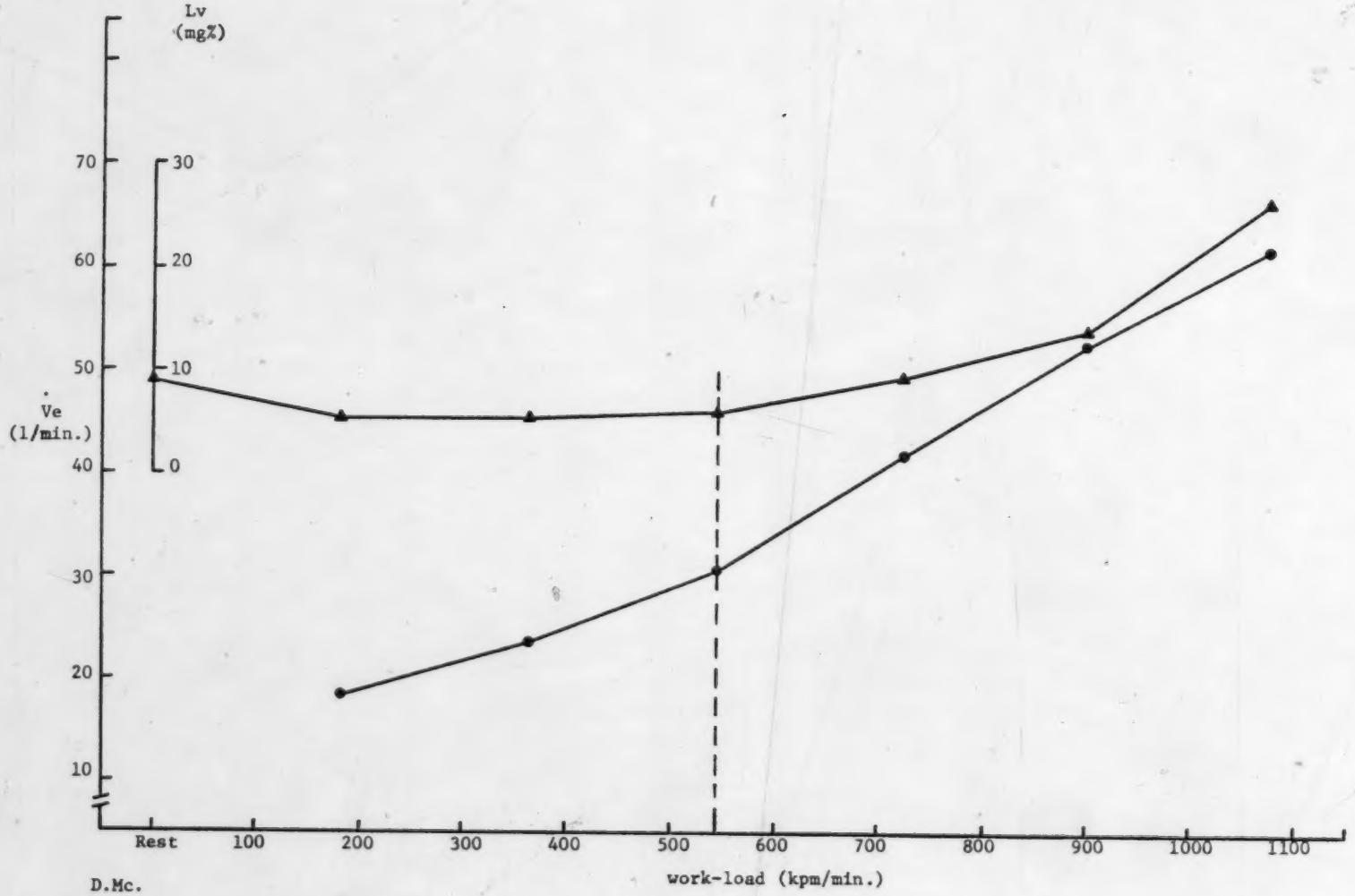

Lv
(mgZ)
50
40
30
20
10
0
90
80
70
60
50
40
30
Ve
(1/min.)
Rest
100
200
300
400
500
600
700
800
900
1000
1100
work-load (kpm/min.)
J.J.

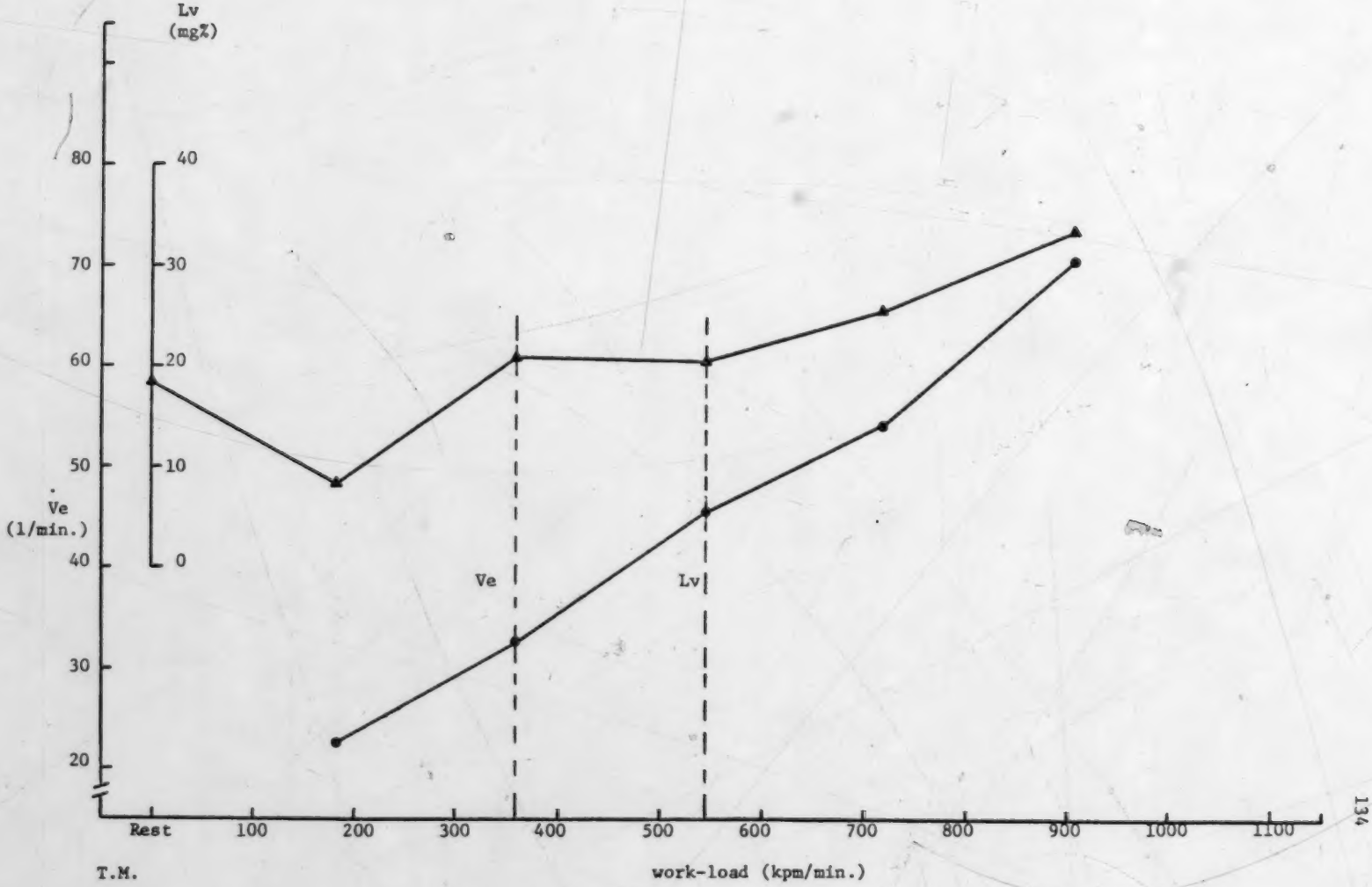

Lv
(mg%)
40
30
20
10
0
90
80
70
60
50
40
30
20
Ve
(l/min.)
Rest
100
200
300
400
500
600
700
800
900
1000
1100
work-load (kpm/min.)

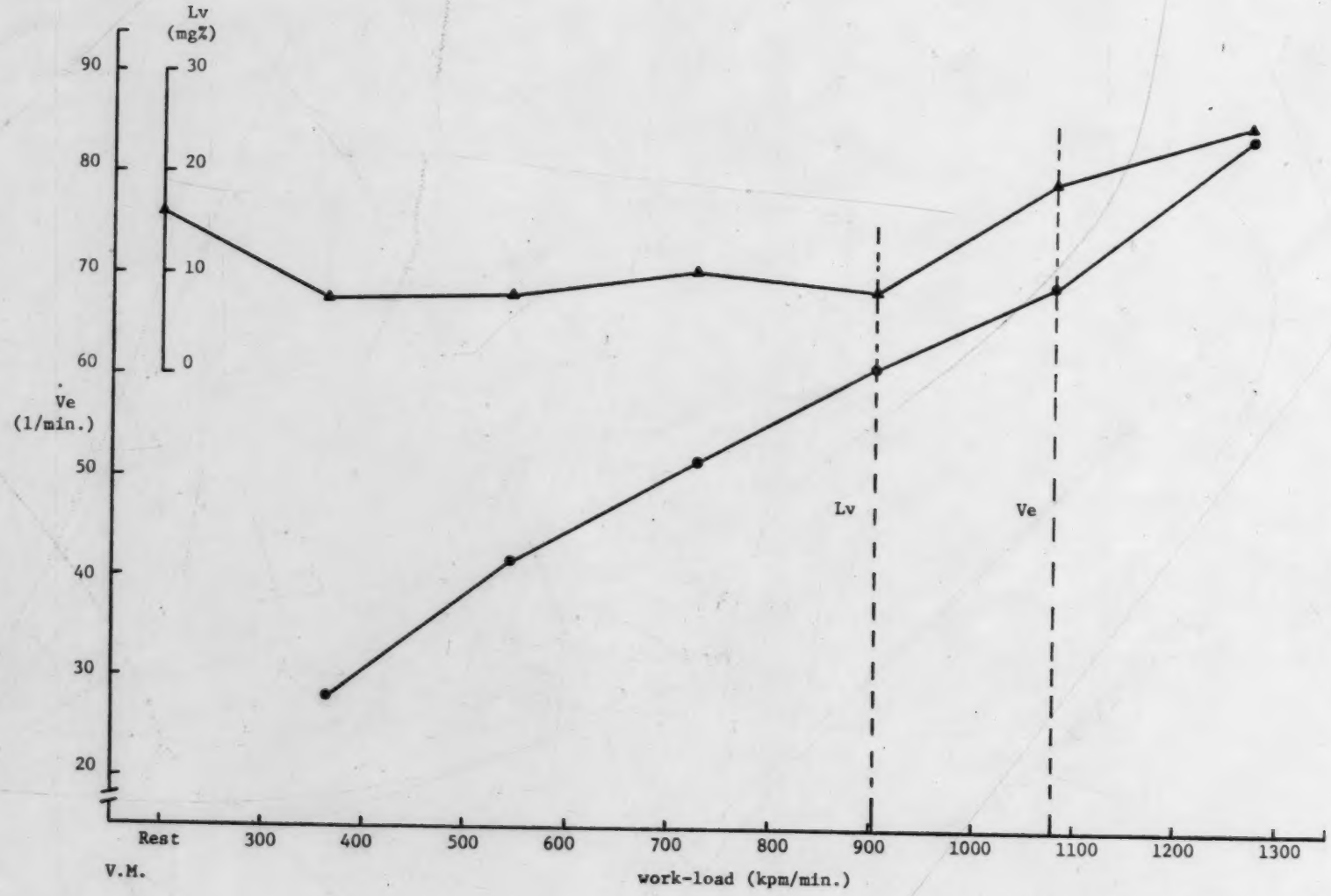
H.K.

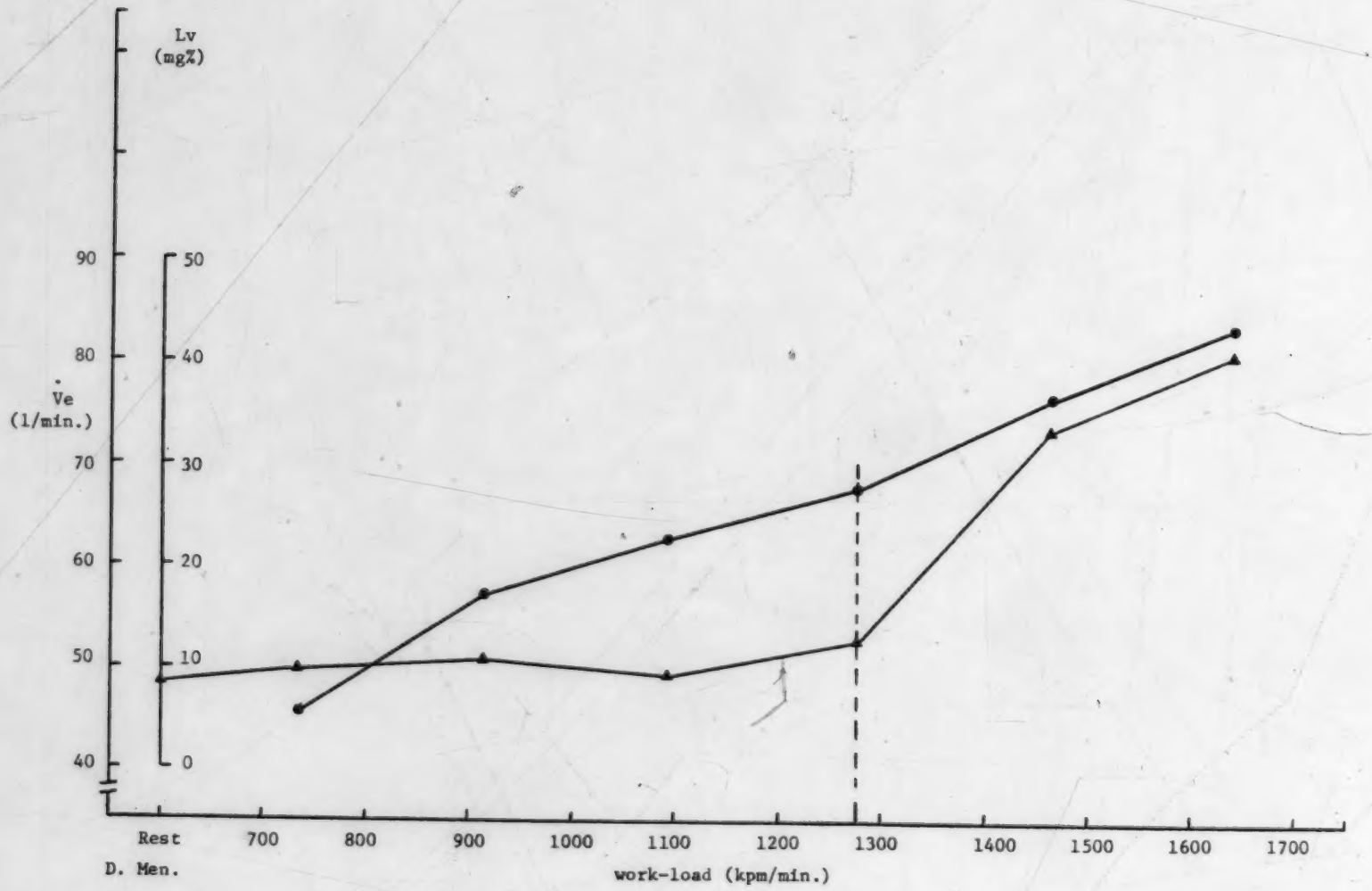

Lv
(mg%)
80
70
60
50
40
30
20
50
40
30
20
10
0
Ve
(l/min.)
Rest
100
200
300
400
500
600
700
800
900
1000
1100
T.K.
work-load (kpm/min.)

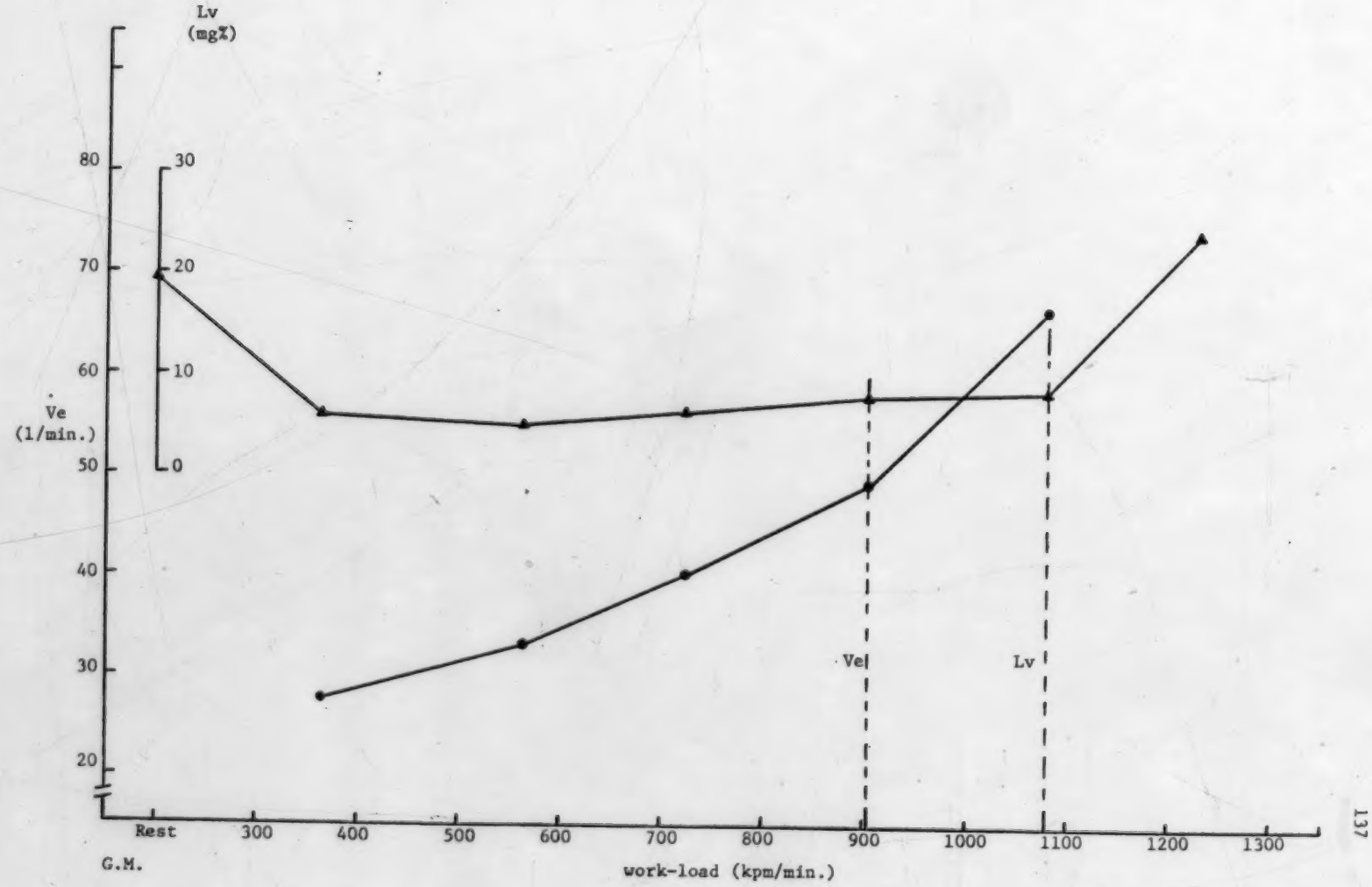

Lv
(mg%)
80
70
60
Ve
(l/min.)
50
40
30
20
50
40
30
20
10
0
Lv
Ve
Rest
100
200
300
400
500
600
700
800
900
1000
1100
J.L.
work-load (kpm/min.)

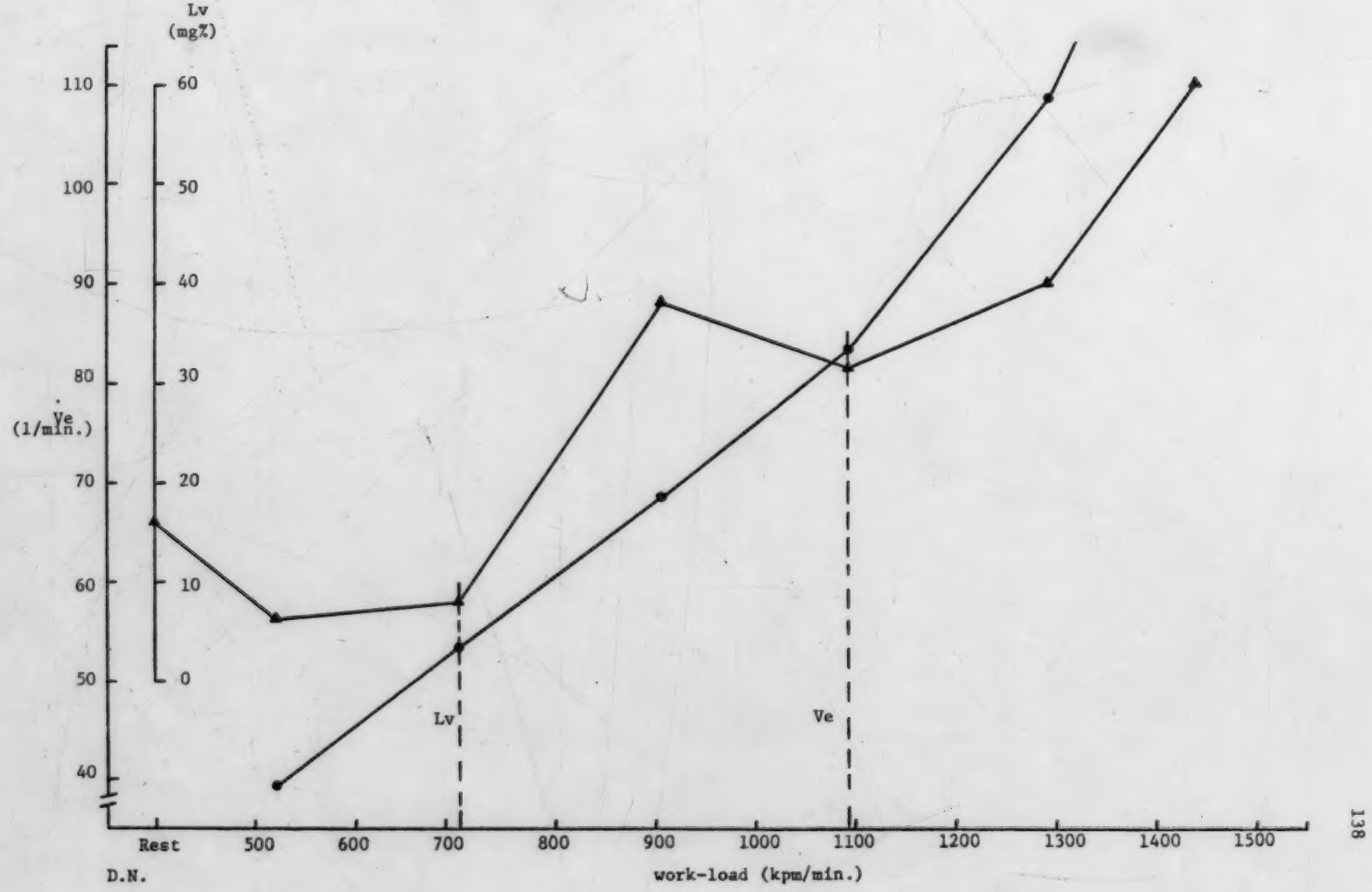

Lv
(mgZ)
70
60
50
40
30
20
10
30
20
10
0
Ve
(l/min.)
Rest
100
200
300
400
500
600
700
800
900
1000
1100
work-load (kpm/min.)
D.Mc.

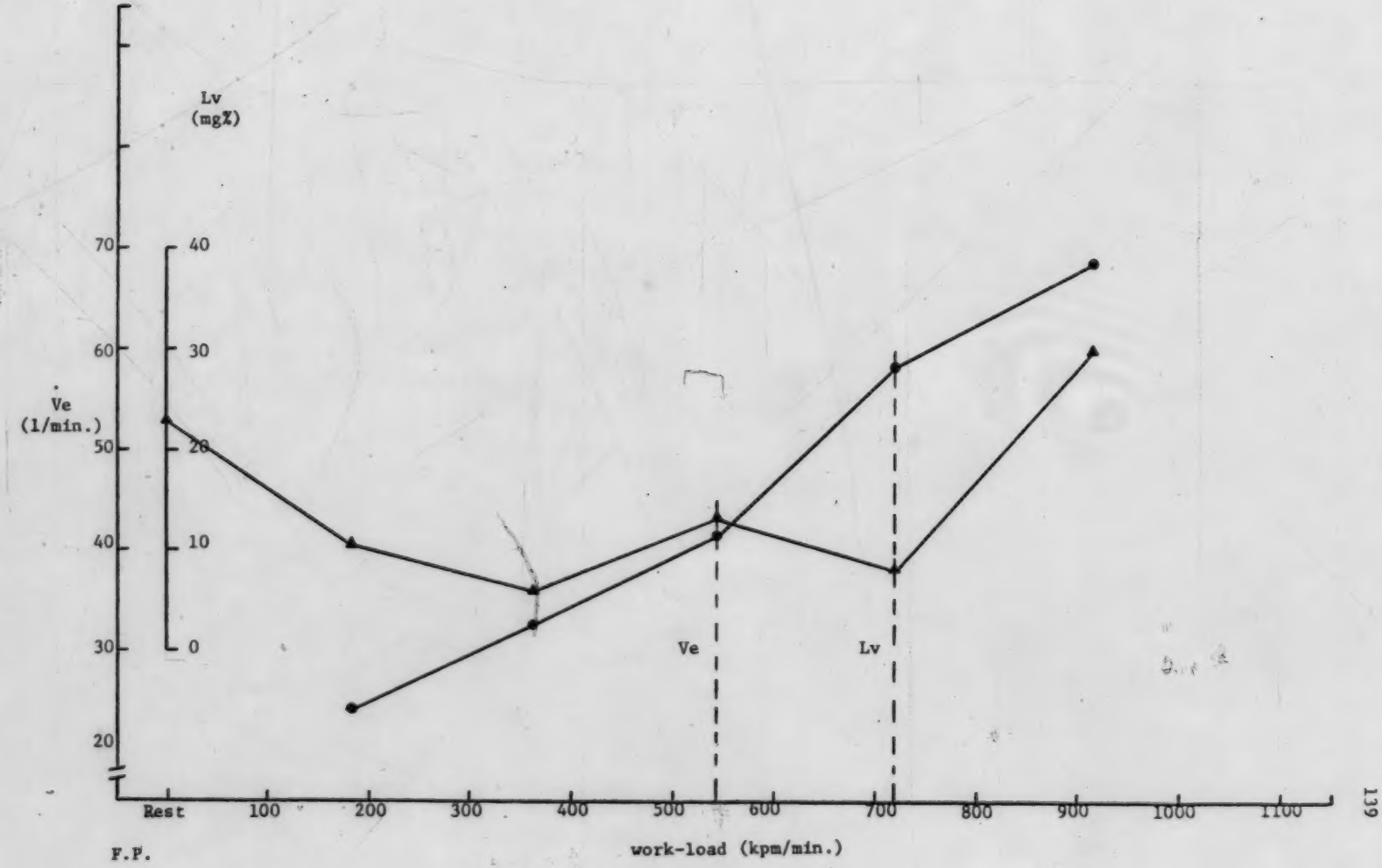

Lv
(mg%)
40
30
20
10
0
80
70
60
50
Ve
(l/min.)
40
30
20
Ve
Lv
Rest
100
200
300
400
500
600
700
800
900
1000
1100
T.M.
work-load (kpm/min.)


Lv
(mg%)
30
20
10
0
90
80
70
60
Ve
(l/min.)
50
40
30
20
Lv
Ve
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
V.M.
work-load (kpm/min.)

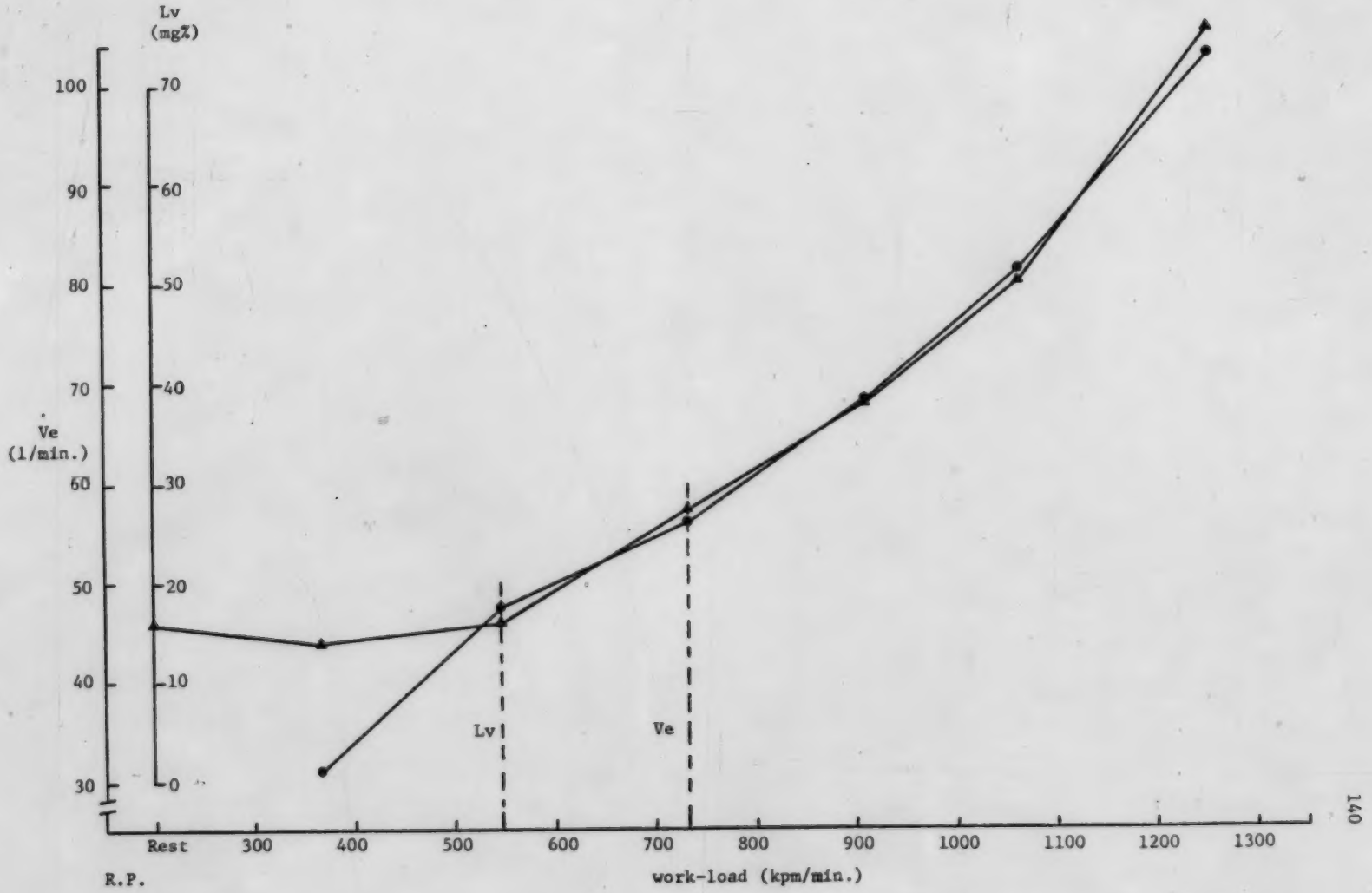

Lv
(mg%)
90
80
70
60
50
40
50
40
30
20
10
0
Ve
(1/min.)
Rest
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
D. Men.
work-load (kpm/min.)

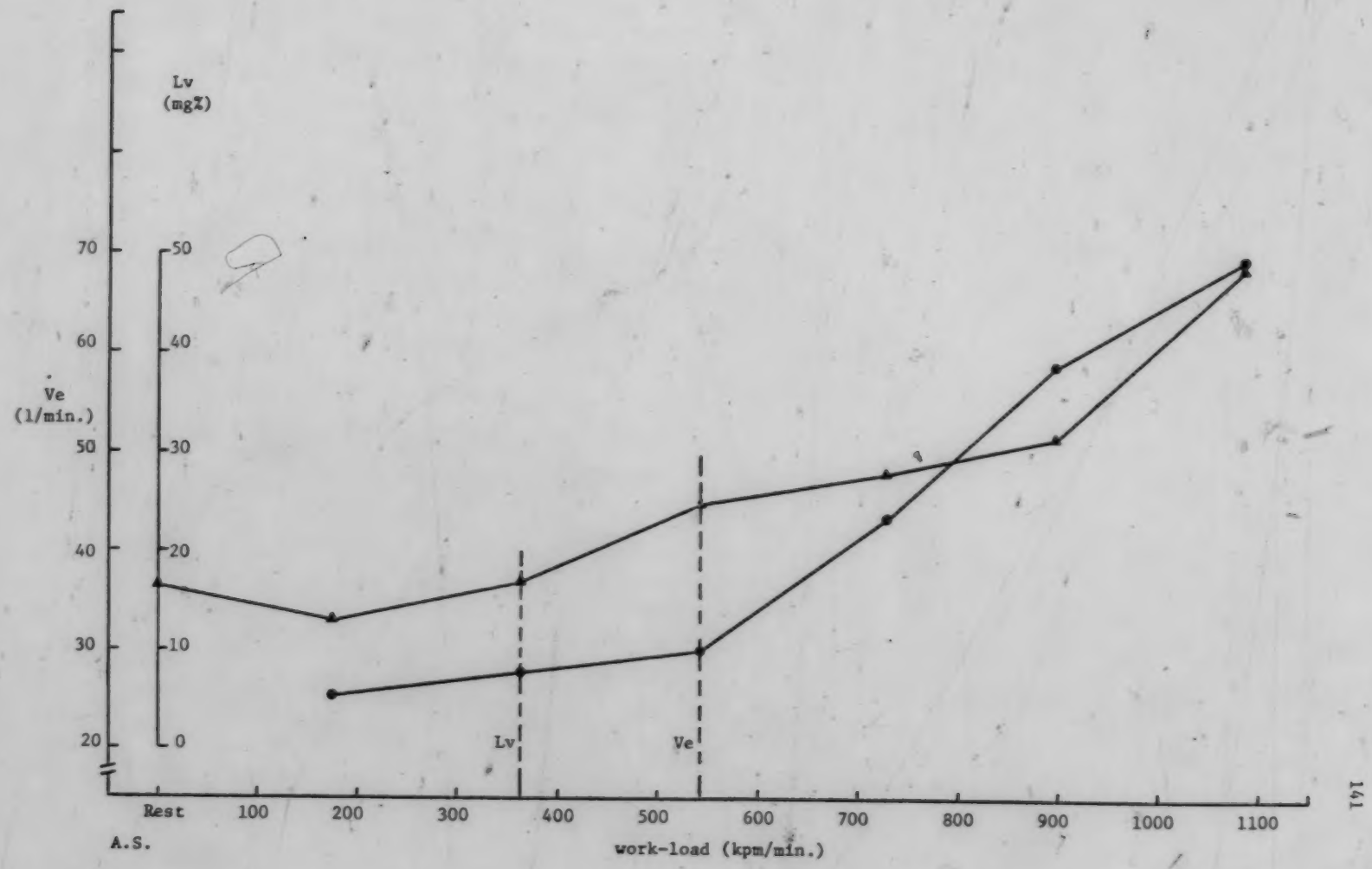

Lv
(mg%)
80
70
60
30
20
10
0
Ve
(1/min.)
50
40
30
20
Ve
Lv
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
G.M.
work-load (kpm/min.)

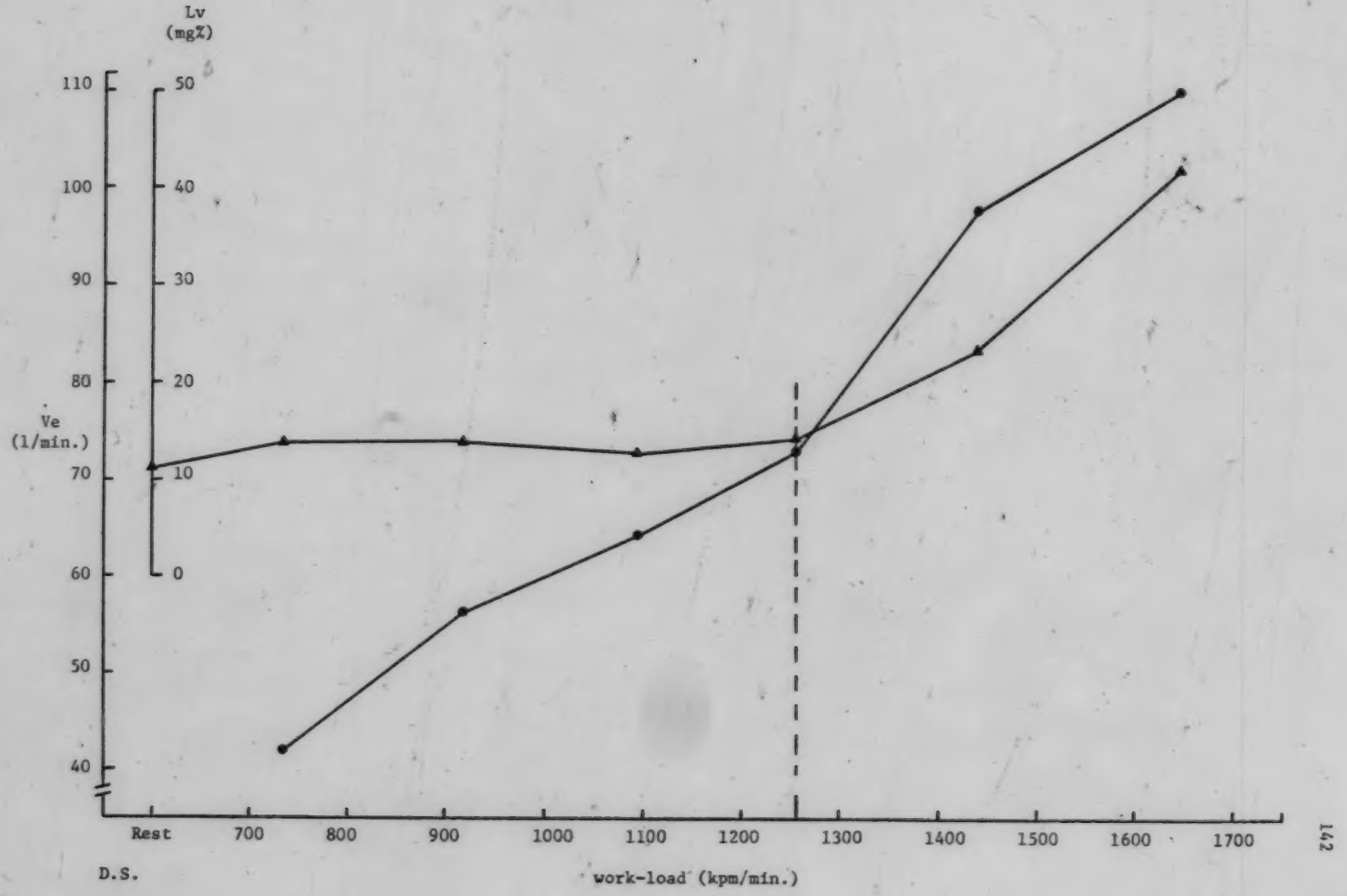

Lv
(mg%)
60
50
40
30
20
10
0
110
100
90
80
70
60
50
40
V̇e
(l/min.)
Lv
Ve
Rest
500
600
700
800
900
1000
1100
1200
1300
1400
1500
D.N.
work-load (kpm/min.)


Lv
(mg%)
70
60
50
40
30
20
40
30
20
10
0
Ve
(l/min.)
Ve
Lv
Rest
100
200
300
400
500
600
700
800
900
1000
1100
work-load (kpm/min.)

F.P.


Lv
(mg%)
100
90
80
70
60
50
40
30
70
60
50
40
30
20
10
0
Ve
(l/min.)
Lv
Ve
Rest
300
400
500
600
700
800
900
1000
1100
1200
1300
R.P.
work-load (kpm/min.)


Lv
(mg%)
70
60
50
40
30
20
50
40
30
20
10
0
Ve
(l/min.)
Lv
Ve
Rest
100
200
300
400
500
600
700
800
900
1000
1100
A.S.
work-load (kpm/min.)


Lv
(mgZ)
110
100
90
80
Ve
(l/min.)
70
60
50
40
50
40
30
20
10
0
Rest
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
work-load (kpm/min.)

D.S.